Barnegat Bay—Year 2

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June, 2015

Final Progress Report for the NJDEP Barnegat Bay Project Year 2 (2013)

Project Title: "Benthic-pelagic coupling: hard clams as indicators of seston in the Barnegat Bay-Little Egg Harbor estuary: a follow-up study"

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Background and Justification.

Mid-Atlantic shallow coastal bays have experienced progressive eutrophication, and environmental degradation, as evidenced by increased macroalgal growth, harmful algal blooms (brown tide), proliferation of gelatinous zooplankton, and loss of submerged aquatic vegetation, SAV habitat. These effects may result in major shifts in food web structure, loss of fisheries, serious decline in ecosystem services, and declining human uses of estuaries.

The Barnegat Bay-Little Egg Harbor estuary (BB-LEH), NJ, system has experienced a historical decline in stocks of the suspension-feeding hard clam (=quahog), *Mercenaria mercenaria*, and in SAV, eelgrass *Zostera marina* and widgeon grass *Ruppia maritima* (Gastrich & Celestino 2003, Kennish et al. 2010). Hard clam populations have also experienced a dramatic decline in other Atlantic coastal lagoonal ecosystems, such as Long Island's south shore estuaries (SSE), NY, and inland MD bays (Chincoteague and Assawoman Bay, MD). The precipitous decline of hard clams in SSE in the 1980s was clearly attributed to overfishing (Kraeuter et al. 2008), but continued decline of this population, despite markedly reduced fishing pressure in recent decades, has led to postulating other potential contributing factors. These include potential changes in the food supply that may lead to poor growth and compromised reproductive success of hard clams (reviewed by Bricelj 2009). It has been speculated that a shift towards smaller phytoplankton (picoplankton, $\leq$ 2 µm size fraction) may have occurred over past decades yet there is limited information on the phytoplankton species composition and size structure in these bays to substantiate this.

The BB-LEH, NJ, which shows a north to south eutrophication gradient (Kennish et al. 2007), has experienced brown tides of the picoplanktonic pelagophyte *Aureococcus anophagefferens* (Gastrich and Celestino 2003), as well as high abundances of other "small forms" such as the chlorophyte *Nannochloris atomus* and blue green alga *Synechococcus sp*. (Olsen and Mahoney 2001; Mahoney et al. 2006), which are poorly captured and digested by hard clams (Bricelj et al. 1984). *Aureococcus anophagefferens* attained high peak bloom densities exceeding $1x10^6$ cells ml^{-1} in 1995, and over four consecutive years between 1999 and 2003 (reviewed by Bricelj et al. 2012). More moderate cell densities ($\leq$ 200,000 cells ml^{-1}) were documented in 1988, 1997, 2003 and 2004, but routine monitoring for brown tide in BB-LEH ceased after that. Typically the greatest prevalence of BT has occurred in LEH and the southern portion of BB (Olsen and Mahoney 2001). Feeding inhibition of juvenile hard clams occurs at *A. anophagefferens* densities $\geq$ 35,000 cells ml^{-1}, and growth ceases above a threshold cell density of 400,000 cells ml^{-1} (Bricelj et al. 2004). Biosphere Inc., a commercial aquaculture facility in Tuckerton, LEH (no longer existing following damage by Superstorm Sandy in 2012), reported mortalities of larval hard clams and growth arrestment of juveniles during a 1995 brown tide. Furthermore, toxicity of an *A. anophagefferens* strain (CCMP 1794) isolated from Barnegat Bay in 1997 was confirmed via a bioassay which measures the reduction in clearance rate of juvenile mussels. The toxicity of the Barnegat Bay isolate was lower than that of a Long Island isolate (Bricelj unpublished data). It is noteworthy that peak densities in mid-Atlantic estuaries typically occur between mid-May and early June, thus coinciding with the period of major spawning of *M. mercenaria* at this latitude, although secondary, lower-intensity blooms can also occur in the fall. Since deleterious effects of growth of hard clam larvae can occur at relatively low densities (~50,000 cells ml^{-1}) that do not cause discoloration of the water column (Bricelj and MacQuarrie 2007), the impact of brown tide on recruitment of suspension-feeding bivalves, including hard clams and oysters, in the BB-LEH system in recent years remains unknown.

Shifts in the phytoplankton community associated with eutrophication of coastal bays can have serious long-term effects on higher trophic levels, including commercially valuable shellfish. Proliferation of a number of harmful algal species has occurred in mid-Atlantic shallow bays: brown tides in SSE, BB-NEH, blooms of *Cochlodinium polykrikoides* in the Peconic estuary, NY (Gobler et al. 2008), and since 2006, annually recurring red tides caused by *Alexandrium fundyense*, producer of paralytic shellfish toxins, in the Huntington-Northport estuary, NY (Hattenrath et al. 2010). Changes from diatom/dinoflagellate dominance to greater abundances of microflagellates, small chlorophytes and the bloom forming *Aureococcus anophagefferens* have been attributed a role in the reduction in shellfish resources, such as bay scallops, *Argopecten irradians*, hard clams, *Mercenaria mercenaria* and oysters *Crassostrea virginica* in Long Island, NY, bays (Bricelj and Lonsdale 1997). As primary consumers, suspension-feeding bivalves, are particularly vulnerable to changes in phytoplankton species composition. In turn their reduced grazing pressure due to reduced population abundance has been attributed a role in the development of algal blooms. When bivalve populations are abundant they can alter the phytoplankton species composition and size structure in shallow estuaries (Cerrato et al. 2004, Lonsdale et al. 2009).

Recent, short-term studies indicate that there are strong spatial gradients in food quality/quantity across Long Island SSE, NY, and Sandy Hook Bay, NJ, during years of no or low brown tide. These gradients are associated with marked differences in hard clam production (Newell et al. 2009, reviewed by Bricelj 2009). The relative contribution of small algae (< 5 μm size fraction) to total phytoplankton biomass, and algal species composition were found to be especially useful in characterizing the food supply for hard clams. Long term water quality monitoring programs typically do not include these measurements. Therefore long-term patterns (e.g. a shift towards dominance by picoplankton) that may relate to eutrophication and/or climate change in these estuaries remain unknown. Additionally, modeling (Hofmann et al. 2006) and empirical data have shown that the food supply for benthic suspension-feeders such as *M. mercenaria* remains ill-defined, and larval model simulations showed that variation in food quality had much greater effects on hard clam larval metamorphic success than changes in temperature and food quantity (Bricelj 2009). New monitoring tools other than total Chlorophyll *a* (Chl *a*) alone as a measure of total phytoplankton biomass, and rapid, real-time measures of phytoplankton composition are clearly necessary.

The ecosystem services provided by suspension-feeding bivalves, including the control of phytoplankton biomass and structure in shallow estuaries has been demonstrated in key ecosystems nationwide (e.g. Cloern 1982). The value of bivalves as indicators of pollution and environmental perturbation, due to their sessile habit and high filtration rates, is also well established by the Mussel Watch Program (Kimbrough et al. 2008). Hard clams, especially during juvenile stages when their growth response is most rapid, can thus provide an ideal indicator of the food supply and other environmental factors in shallow, Atlantic coastal lagoonal estuaries that, due to their relatively long residence times, are particularly susceptible to the effects of nutrient enrichment. As a commercially important, native shellfish species, *M. mercenaria* has been the focus of population enhancement efforts in Great South Bay, Long Island, NY (Doall et al. 2008) and to a lesser extent in BB-LEH (Barnegat Bay Shellfish Restoration/ReClam the Bay, through Rutgers Cooperative Extension of Ocean County (reviewed by Bricelj et al. 2012). **Future investment and management decisions on the value, scale and siting of**

shellfish restoration efforts relies on demonstrating that present environmental conditions (especially the food supply) in these bays is adequate to support self-sustaining populations.

Project Goals and Objectives

The overall goal of this study was to characterize environmental factors, namely temperature, salinity and seasonal quality and quantity of suspended particulate matter (seston) for bivalve suspension-feeders in the BB-LEH estuary using the hard clam, *Mercenaria mercenaria*, a shellfish species that once supported major commercial and recreational fisheries in this ecosystem, as a biosensor. Specific objectives were to assess the response of juvenile hard clams over a spatial range of environmental conditions at four contrasting field sites in LEH-BB by measuring the clams' *in situ* seasonal growth and condition in relation to key characteristics of the seston/food supply, especially phytoplankton biomass, and composition based on photopigment analysis of major functional taxonomic groups (FTGs) This follow-up study provides a 2nd year of data for comparison with that obtained in 2012.

An additional objective was to provide a direct comparison between FTG analysis and microscopic species identification of phytoplankton. Although this direct comparison from split samples collected at the same site/time, was only available for two of the study sites (Sedge and IBSP), a comparison was also made between our FTG results at Tuckerton Cove and those of phytoplankton taxonomy determined microscopically at a neighboring NJDEP water quality station (Figure 1). Microscopic analysis of the phytoplankton community at a subset of these stations (three to four) was conducted by Ling Ren, Philadelphia Academy of Natural Sciences at Drexel, in 2013 (biweekly sampling between April and September) via a separate NJDEP-funded project. The present study thus represents a first attempt to apply and evaluate the value of photopigment analysis, a more automated/rapid and less costly method of phytoplankton analysis, in the BB-LEH estuary.

The information generated allows comparison of present environmental conditions for growth of hard clams, a representative suspension-feeding bivalve, along a north to south transect within the hard clams salinity-tolerance regime during the clams' growth season. The present study thus provides an alternate index of water quality for the BB-LEH estuary that complements indices used to date, such as dissolved oxygen (DO) and SAV condition. Results help to determine whether poor food quality is a contributing factor to the poor recruitment of hard clams in BB-LEH, one of several factors, including high predation pressure and/or poor fertilization success due to limiting densities of adults, that have been suggested as the cause of the decline of hard clam populations in mid-Atlantic coastal lagoons (Bricelj 2009).

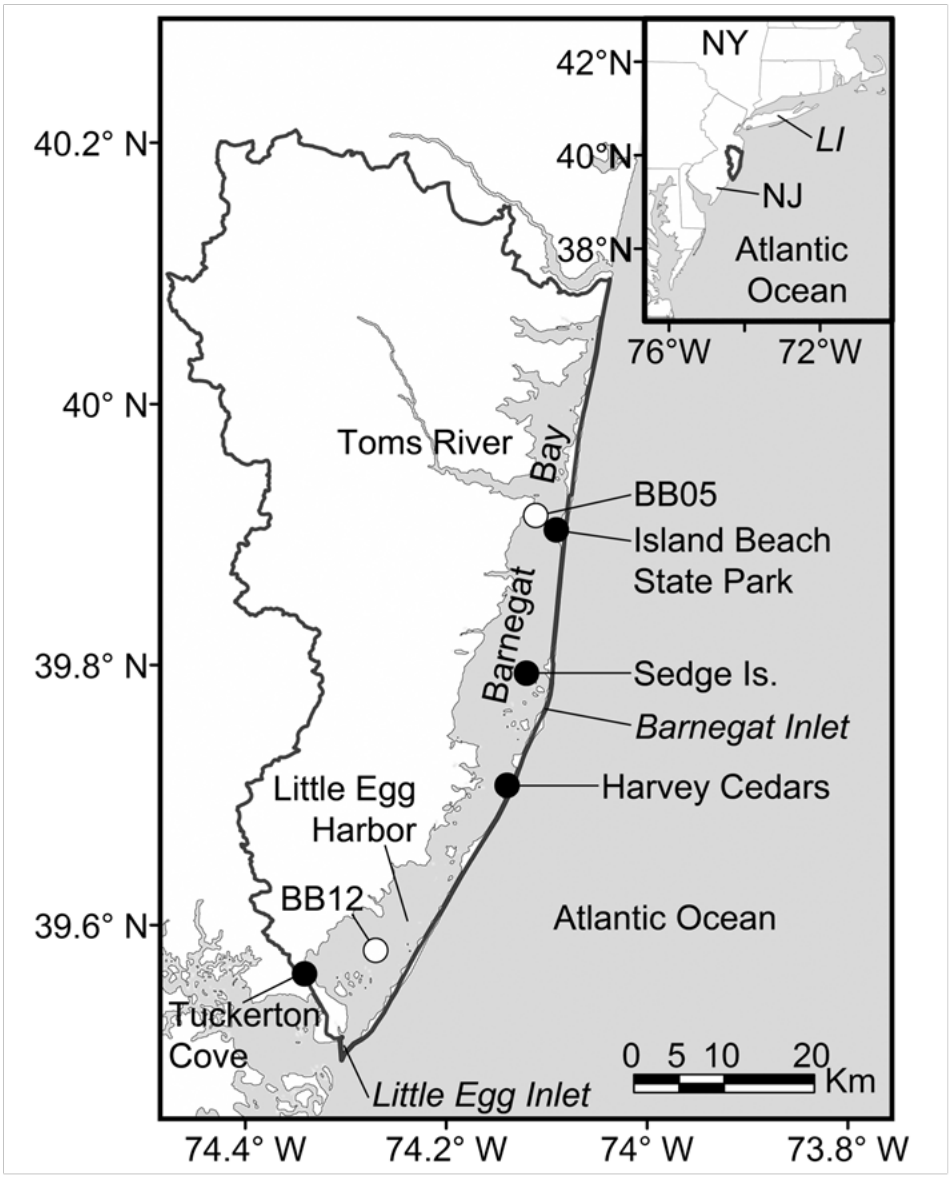
This work can be expanded in future years to provide increased spatial resolution within the bay (e.g. west to east transects), and determination of longer-term, climate driven changes in the LEH-BB lagoonal ecosystem. The study is not intended to provide growth parameters that can be directly extrapolated to adult hard clams or their larval stages, which can differ in their food requirements, but rather to use juvenile hard clams, which provide a rapid growth response, as indicators of temporal and spatial water quality conditions within this estuary. Finally, results of this study are useful to assess whether current, site-specific environmental conditions can support a future expanded hard clam restoration effort.

Methods

Study sites. Study sites within BB-LEH in 2013 were the same as in 2012, and span a range of environmental conditions based on information derived from existing NJDEP water quality monitoring programs and our own sampling in 2012. Clam deployment in areas that were subject to minimal clamming activity and disturbance by the public were a consideration in final site selection. All the sites occurred in relatively shallow water (≤ 2-3 m) and were selected in shellfish approved waters. It is well known that *M. mercenaria* is relatively intolerant of salinities below ~15 (reviewed by Grizzle et al. 2001). Therefore, study sites were selected within the zone of salinity tolerance of hard clams, and within areas of known occurrence of hard clams based on previous surveys (e.g. Gastrich and Celestino 2003) (Figure 1).

Figure 1. Barnegat Bay-Little Egg Harbor (BB-LEH) ecosystem, NJ. Black circles indicate sites selected for off-bottom deployment of juvenile hard clams. The Sedge Island site is found within the Marine Conservation Zone (MCZ). Inset shows the location of the BB-LEH coastal lagoon in the mid-Atlantic US.

GIS coordinates are as follows: IMBS site: 39°54' 20.2818"N/74°05'16.209"W; Sedge Island site: 39°47' 40.5"N/74°07' 06.8"W; Harvey Cedars: 39°42' 30.45"N/74°08'16.24"W; Tuckerton Cove: 39°33'48.51"N/74°20'23.07"W. BB05 and BB012 are NJDEP water quality monitoring sites where phytoplankton species abundance and composition were characterized as part of a parallel study conducted in 2013 (Ling Ren, unpublished data).



The sites selected include from north to south (Figure 1):

- Island Beach State Park (IBSP), upper BB, southeast of Toms River. This site is characterized by lower salinities compared to the other three sites listed below (i.e., mean salinity = 22.75 during the summer of 2013, see below).
- Sedge Island Marine Conservation Zone (Sedge Is., MCZ), central BB, where hard clam seeding, stock enhancement activities have been undertaken since 1996. This area differs from mid-Bay stations as it contains shallow eelgrass beds and, based on our 2012 data, is characterized by lower temperatures and higher salinities than the other three selected sites due to the influence of oceanic water exchanged via the Barnegat Bay Inlet (see Results section below). In 2013 deployment of clam cages site had to be moved from the

dock at the Sedge Is. Education Center, to an adjacent site that required access from the shore, as the dock was destroyed during Superstorm Sandy in fall 2012.

- Harvey Cedars, Long Beach Island, southern BB, a site with a bulkheaded shoreline.
- Tuckerton Cove, on the western shore of LEH. This site was used in the past for clam relaying activities.

Three of the above sites occurred over coarse sandy substrate; the Tuckerton Cove site is characterized by a silty-muddy bottom (although clams were deployed off-bottom to minimize effects of substrate type).

Clam deployment and sampling

Juvenile clams (~8 to 10 mm in initial shell length, SL) were obtained from local, NJ, commercial hatcheries for 2013 trials: George Mathis Clam Farm, Egg Harbor (48 % juveniles of the notata variety) for Trial I, and Bill Avery's Quality Bay Clams, Galloway (82% notata) for Trial II. The clams were deployed for 3 to 4 weeks in bottom cages (18" x 18" x 18" high; n = 5 cages per site), that were divided into 3 levels. Cages were marked by surface buoys and weighed with concrete blocks inserted in the bottom compartment. Clams were contained in bags with a 4 mm square mesh placed in the middle shelf. Each mesh bag contained 300 to 500 juvenile clams depending on initial size, a low density that precludes density-dependent growth inhibition; at each sampling date ~50 clams were removed without replacement from each of 4 to 5 cages). This number was selected based on the mortality rates, variability in size obtained among cages and among individuals within cages in 2012. Cages were deployed throughout the summer and early fall to encompass the main growing period of hard clams. Deployment of clams above bottom was selected for the purposes of this study, to preclude the confounding effects on clam growth of substrate type, near-bottom sediment resuspension, and also to minimize potential access by bottom predators.

The study period was divided into two trials: Trial I started on June 4th, 2013 and ended on July 10th, 2013. The mean shell length of the clams at the time of deployment was 8.99 mm +/- standard error, SE = 0.077 (n = 100 clams). Trial II started on August 12th, 2013 and ended on September 11th, 2013. The mean initial shell length of the clams in this Trial II was 8.81 mm +/- SE = 0.093 (n = 50).

Clam survival, shell and tissue growth rate, and condition index were determined on a weekly basis during each deployment period. Clam survival was determined *in situ* based on the number of empty valves, but any additional dead individuals not identified by this method were confirmed by prying open the shells upon arrival to the laboratory at the time when soft tissues were dissected.

Both absolute ($\mu m\ day^{-1}$ in shell growth) and relative shell and soft tissue growth rates were calculated. The latter was calculated as the instantaneous growth coefficient (% change day^{-1}), $k = [\ln X_f - \ln X_o)/\text{time interval in days}] \times 100$, where X_f and X_o are the mean, weekly final and initial shell length, SL, or soft-tissue dry weights (DW) of clams in each cage. This parameter provides a relative measure of growth and reduces the confounding effect of initial clam size. Shell length was determined with digital calipers from the greatest anterior-posterior dimension. Tissue DW was determined following dissection of tissues and oven drying to a constant weight (24 to 48 h depending on size) at ~ 60^{o}C. Fifty clams for DW and 100 clams for SL were sampled initially. Tissue mass can provide a more sensitive parameter to measure growth rates than the increase in SL, and can also reflect weight loss during periods of poor food supply.

Individual tissue DW was determined with a Cahn electrobalance (±0.1 μg). An individual, allometric condition index (CI) was determined as: CI = (mg total body ash-free AFDW) (mm SL)$^{-3}$ × 1000, which assumes that organic matter to length scales approximately as SL^3 (Clausen and Riisgård 1996, Bricelj et al. 2004). Ash weight to calculate AFDW was determined following overnight combustion at 480^{o}C in a muffle furnace.

Fouling of cages and mesh bags containing clams was documented weekly from observations and photographs taken at each site (see Figure 16 below). Both cages and mesh bags were scrubbed of fouling organisms on a weekly basis to reduce fouling to a minimum and thus prevent confounding effects on clam growth and survival.

Water column sampling of particulates

In situ growth of juvenile clams was related to the quantity and quality of the suspended food supply, including phytoplankton biomass (total Chlorophyll *a* concentration), composition (from FTG analysis) and the contribution of "small forms" (pico-coccoids < 2-3 μm in diameter) to total phytoplankton bio-volume, determined microscopically at Sedge and IBSP. Water samples were collected weekly during the period of clam deployment with a self-powered, Masterflex peristaltic pump to minimize damage/disruption of algal cells and disturbance/sediment resuspension from the bottom. Water was collected from approximately the same off-bottom height as that of clam deployment, in two 10 L plastic containers, and transported in coolers on ice to either the Rutgers University Jacques Cousteau facility, Tuckerton, for seawater collected at the two southern stations, and to the IBSP Forked River Interpretive Center for samples at the two northern stations. Seawater was processed by low-vacuum filtration (≤ 15 psi) of known volumes of the suspension (measured with a graduated cylinder) on 2.4 cm diameter Whatman GF/F glass-fiber filters (or GF/C filters for particulate organic and inorganic matter (POM, PIM, and carbon and nitrogen) using a multi-port filtration setup, following sieving through a coarse 153 μm Nitex mesh sieve to remove large zooplankton and detrital particles. Temperature was determined continuously at the study sites with *in situ* temperature HOBO Onset data loggers directly attached to one cage at each site. Discrete temperatures and salinities were also determined at the time of sampling at the 4 sites with a hand-held thermometer and refractometer, respectively.

The following metrics were used for characterization of suspended particulates (seston) to relate to clam growth: a) **total chlorophyll *a* (Chl *a*)**, b) **total particulate organic matter (POM) and particulate inorganic matter (PIM)**, the latter used as a measure of suspended sediments concentrations and turbidity, c) **particulate organic carbon and nitrogen (POC and PON)**, and d) p**hytoplankton functional taxonomic groups (FTGs)** determined from diagnostic photopigments of major microalgal groups (e.g. chlorophytes, cyanobacteria, diatoms, cryptophytes, dinoflagellates) (Paerl et al. 2003, 2005, 2007). The pigment 19'butanoyloxyfucoxanthin (19'but), although not exclusive to *A. anophagefferens* (Glibert et al. 2007), can provide an estimate of the abundance of pelagophytes in the system, and thus was used as an indicator of the presence of *A. anophagefferens*. Gluteraldehyde fixed seawater subsamples from selected dates/sites collected in 2012 and 2013 were also shipped to Chris Gobler's laboratory at Stony Brook University, NY, to determine *A. anophagefferens* concentrations by immunofluorescence and enumeration by flow cytometry (Stauffer et al 2008). The above multiple parameters were used as an indicator of the food supply as there is typically no single good indicator of the food resource for suspension-feeders. Photopigment analyses had also been conducted in 2012 but

analysis was funded by The Barnegat Bay Partnership; in 2013 the FTG analyses were conducted as part of the NJDEP-supported project.

Photopigments were analyzed by high-performance liquid chromatography (HPLC) coupled with in-line photodiode array spectrophotometry. This method is reliable, consistent, and ideally suited for large numbers of samples (Paerl et al. 2003, 2007). Total phytoplankton biomass, measured as Chl *a* was partitioned into the phytoplankton taxonomic groups to quantify the relative and absolute contributions of each group (Mackey et al. 1996). All HPLC analyses were conducted at the Institute of Marine Sciences, University of North Carolina (UNC)-Chapel Hill under the direction of Dr. Hans Paerl. Seawater samples were filtered on site, frozen and shipped overnight on dry ice to UNC. Characterization of FTGs was related to available water quality data (temperature, salinity determined at clam deployment sites), and baywide nutrient data determined by NJDEP at their water quality monitoring sites as well as published data.

All filtered samples were obtained in duplicate or triplicate for each analysis. For total seston, PIM (ash weight) and POM (AFDW), samples were filtered through pre-combusted (overnight at 480°C), pre-weighed Whatman GF/C glass-fiber filters (24 mm diameter), and filters were rinsed twice in situ with 2 ml of an isotonic ammonium formate solution to remove salts that can contribute to the DW. Dry weight and ash weight were determined following oven-drying at ~60^{o}C for 24 h, and overnight combustion in a muffle furnace at 480^{o}C, respectively to allow calculation of AFDW. All filters were folded in half, wrapped in aluminum foil, and transported on ice to the laboratory, where they were stored at –80°C. Samples for POC/PON were obtained by filtering the suspension on pre-combusted Whatman GF/C glass-fiber filters; filters were dried at ~ 60^{o}C and shipped to the University of Maryland's Horn Point laboratories for analysis conducted using an Exeter EAI CE-440 Elemental Analyzer, and acetanilide as standard.

Statistical analysis

Weekly hard clam growth rates at each station were compared using ANOVAs and post hoc Tukey multiple comparisons. All data expressed in percentages, e.g. % instantaneous growth coefficients and % survival were arcsine transformed to meet the assumptions of normality prior to conducting ANOVAs. Linear regression analysis was carried out to determine the relationship between size-standardized growth (k_{DW}) rates and environmental parameters (temperature, salinity and proposed multiple measures of food quality/quantity). A two-way ANOVA compared clam growth rates (k_{DW}) among all sites and weeks throughout the 2013 study period.

The covariance between pigments measured by HPLC was determined using Pearson product-moment correlation coefficients, followed by linear regression analysis. Using values derived from linear regressions and the published literature, FTG-specific contribution to Chl *a* at each site was analysed using CHEMTAX software (Mackey et al. 1996). Linear regression analysis between FTG-specific Chl *a* estimates from CHEMTAX and microscopically derived biovolume measurements were conducted as a means of ground-truthing CHEMTAX results, and to provide insight into the identity of small forms (pico-coccoids) not characterized at the taxonomic level by microscopy.

Results

Physical variables: temperature and salinity

As observed in 2012, during the summer of 2013 water temperatures were consistently lower at Sedge Is. than at the other three study sites. This temperature differential was more pronounced during early summer (June-July during Trial 1) (Figure 2). Higher daily temperature fluctuations were also observed at Sedge than at other sites, as was observed in 2012. The maximum daily variation at Sedge was 16°C day in 2013, compared to 10°C in 2012.

Figure 2. Water temperatures (daily means) determined from continuous records (15 min readings) compared between the 2012 and 2013 study periods (records for Trial I and II are shown in left and right panels, respectively). Note that sampling in the second trial of 2013 started ~2 weeks later than in 2012.

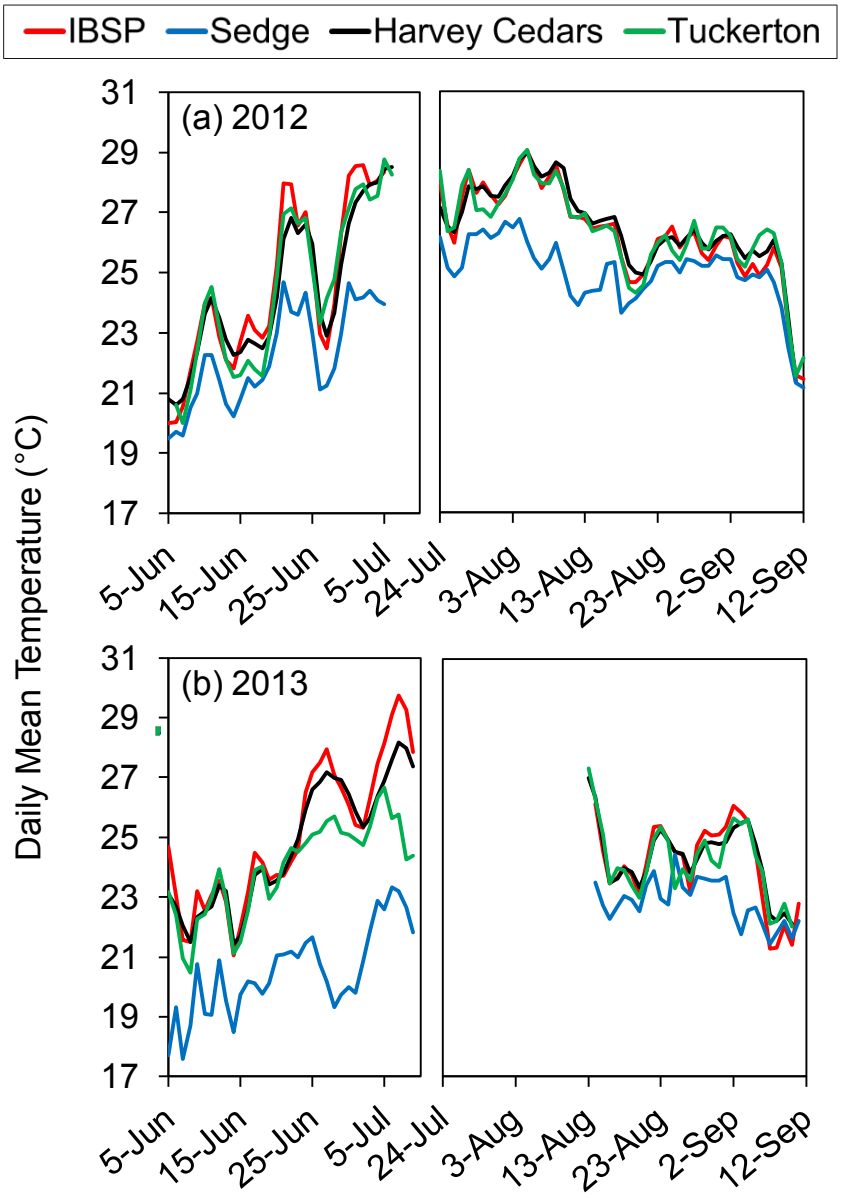


Figure 3. Temperature fluctuations (determined from 2hr-means of measurements obtained every 15 min) at the four study sites during Trials I and II, 2013.

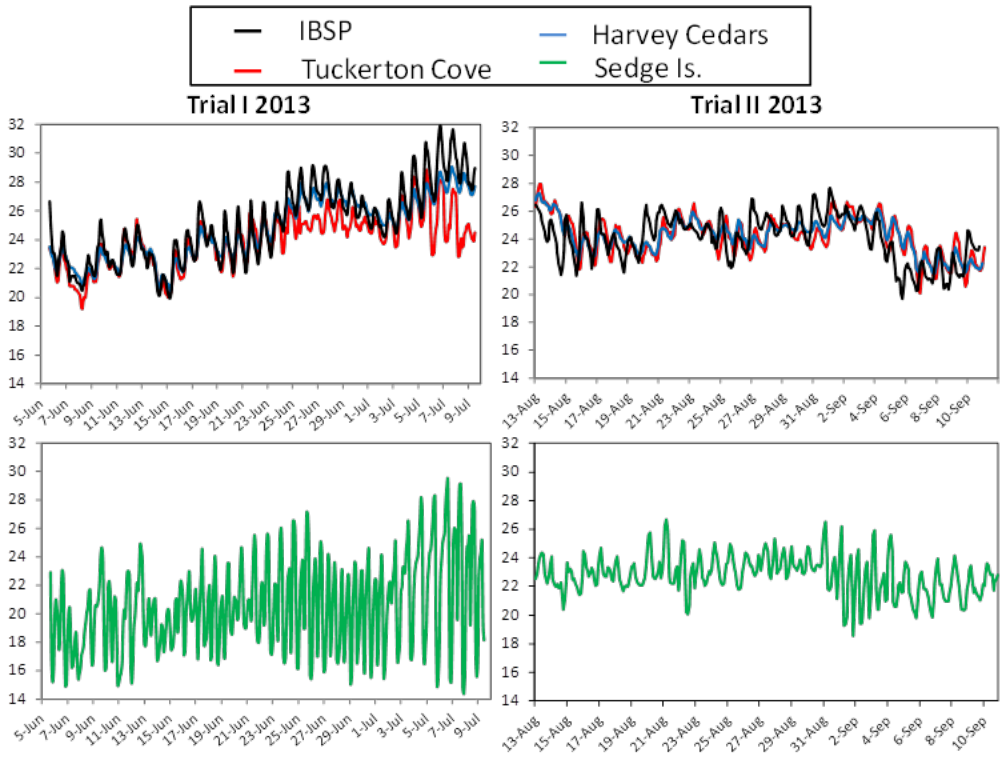
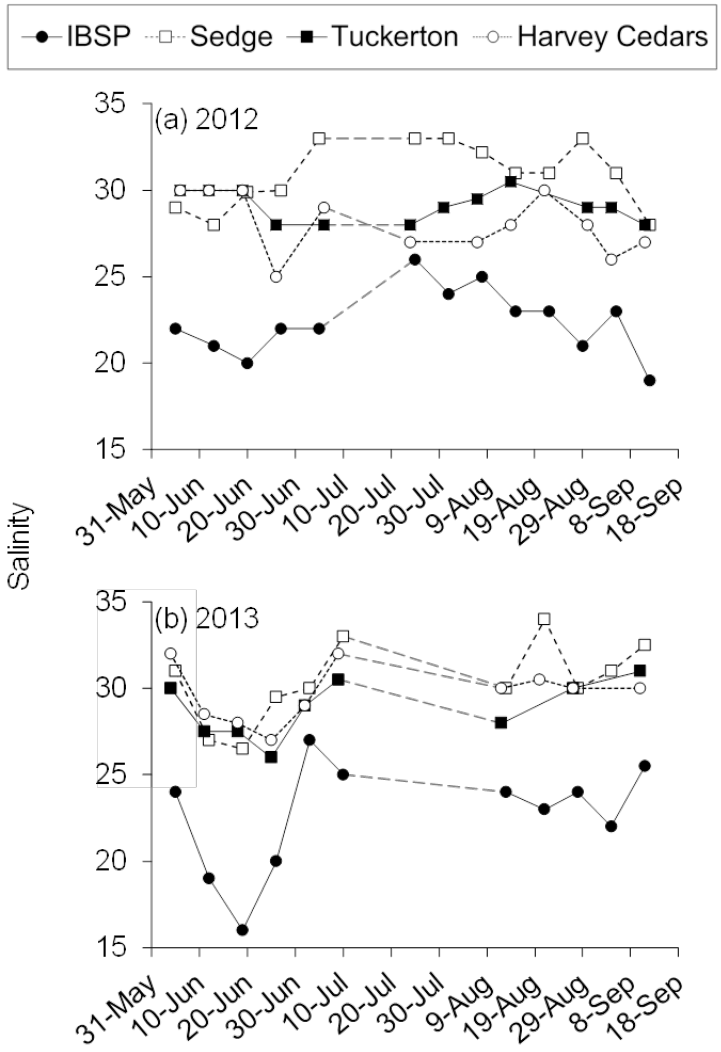


Figure 4. Salinities measured weekly with a refractometer at the four study sites during the 2012 and 2013 study periods. Dashed line indicates the period between Trial I and II deployments when no salinity values were recorded.



Also consistent with 2012 data, mean salinities at IBSP were lower than at the other study sites, reflecting the influence of the Toms River plume (Figure 4). In 2013, however, values at IBSP dropped to a minimum of 16 (Table 1), and this was associated with cessation of growth of juvenile clams (see Figures 13 and 15), whereas the minimum salinity was 18 in 2012. Mean and absolute salinities recorded in 2013 were maximal at Sedge (30 and 33, respectively) reflecting the proximity of the Barnegat Inlet (Table 1).

Table 1. Salinity (weekly means and ranges) determined during the 2013 study period at the four study sites.

Mean	Range	Site
22.75	16-27	IBSP
30.35	26.5-33	Sedge
29.7	27-32	Tuckerton
28.83	26-30.5	HC

Water column seston characteristics

Particulate inorganic matter (PIM) concentrations, largely reflecting suspended sediment concentrations, were highest at the two southern sites, Tuckerton and Harvey Cedars, where mean PIM peak concentrations exceeded 25 mg l^{-1}, attaining a maximum of 26 and 28 mg l^{-1}, respectively Lowest values were recorded at Sedge, where they consistently remained below 8.5 mg l^{-1}. A feature consistent with findings in 2012 was that POM contributed a higher percentage of total seston (i.e. of total DW in mg l^{-1}) at IBSP (mean of 50%), than at the other study sites, where mean POM/DW values were 30%, 26% and 25% at Sedge, Harvey Cedars and Tuckerton, respectively).

Particulate organic carbon and nitrogen concentrations in 2013 (Figure 6) showed comparable patterns to those documented in 2012 (not shown), with generally higher PON and POC concentrations at IBSP, and lowest concentrations at Sedge Is. The POC/PON ratio was also consistently higher at IBSP than at Sedge. The high POC and POC concentrations determined on June 18 at Sedge (Figure 6) coincided with heavy rainfall starting the previous night and during the day of water collection which may have led to bottom resuspension at this shallow site.

Figure 5. Mean concentrations of particulate inorganic matter (PIM) and particulate organic matter (POM) (± standard error, SE; n = 3) determined during the 2013 study period at the four study sites. Note that there was no water column sampling between the two Trials, July 11 to Aug. 11.

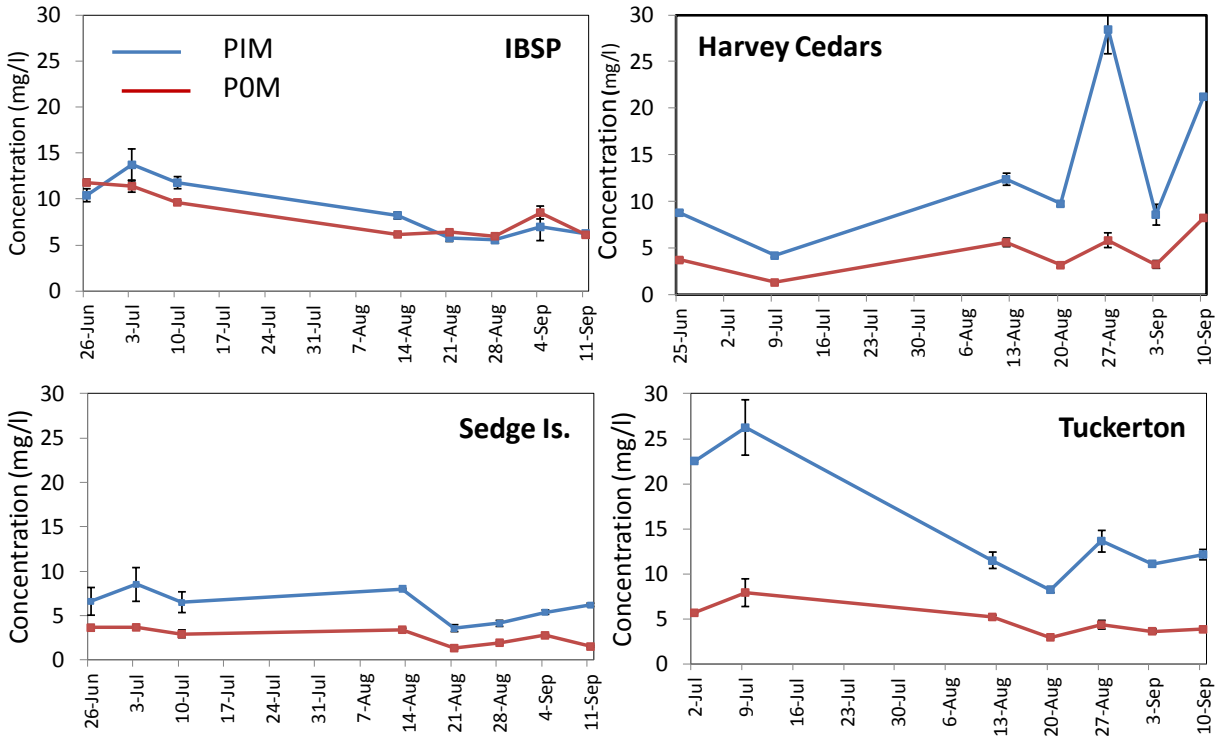


Figure 6. Mean particulate organic carbon (POC, upper graph) and particulate organic nitrogen (PON, lower graph) concentrations (± SE) determined in 2013 at the four study sites. Note that there was no water column sampling between the two Trials, July 11 to Aug. 11.

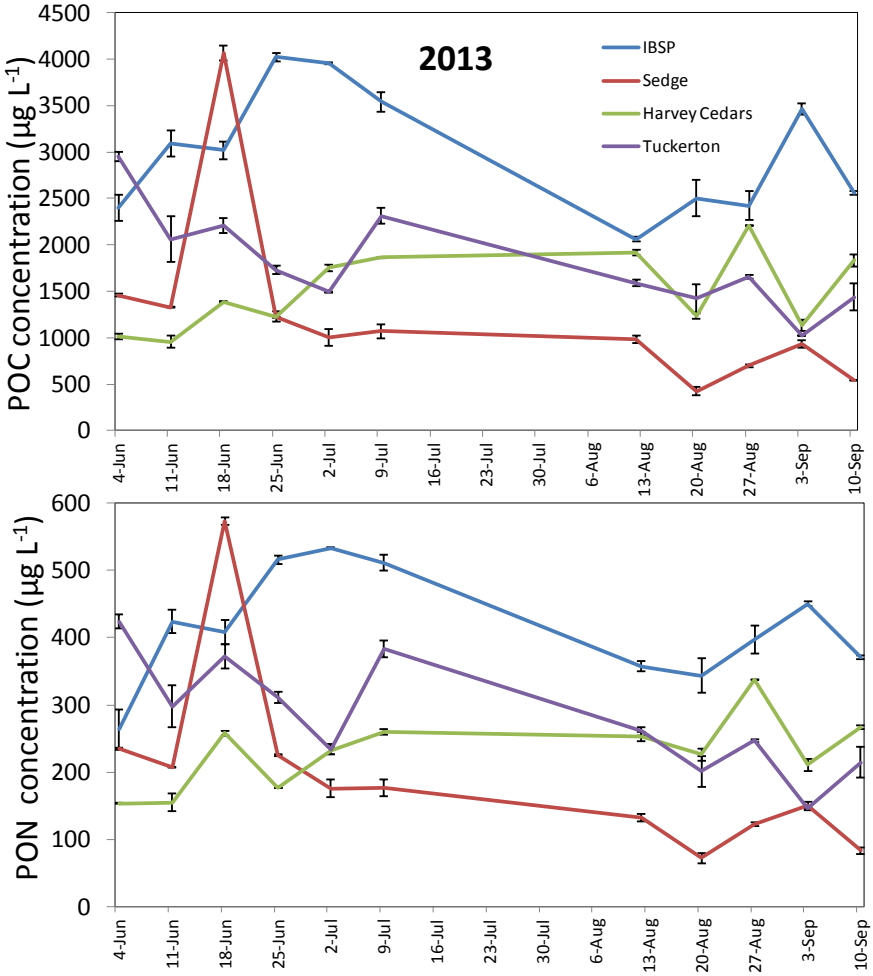
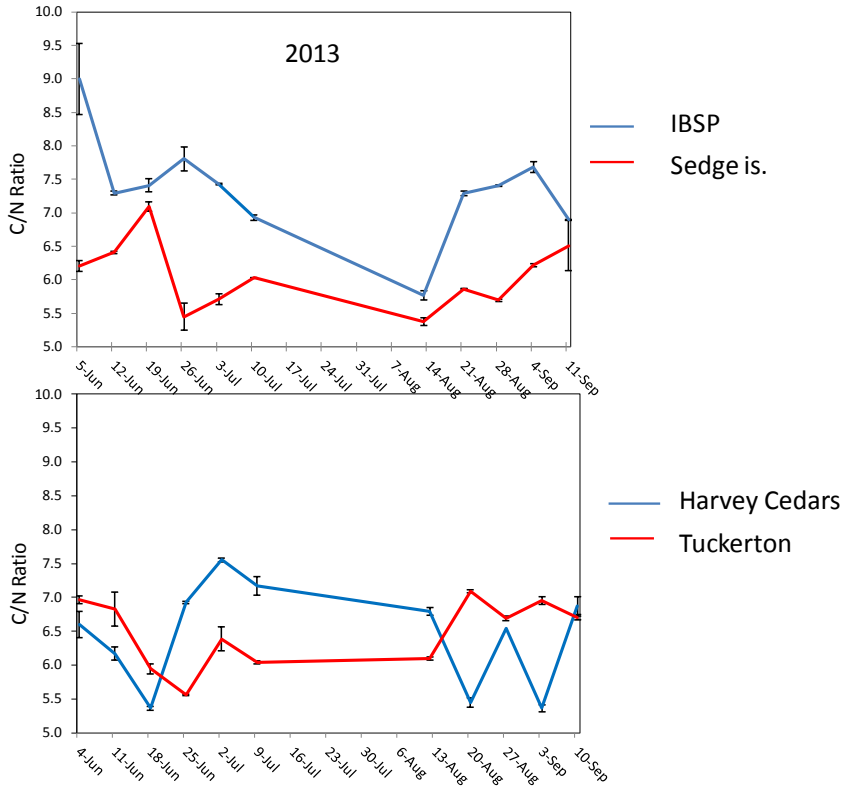
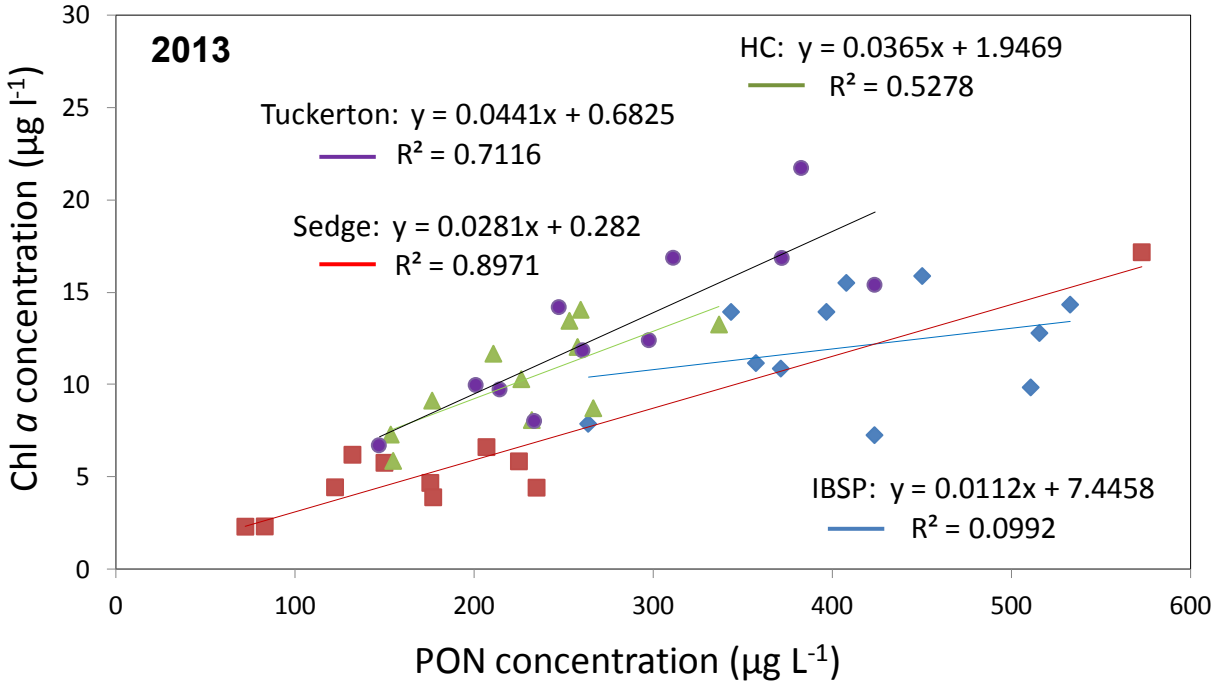


Figure 7. Particulate organic carbon to nitrogen ratio (POC:PON) during the 2013 study period at the two northern sites (IBSP and Sedge, upper graph) and the two southern sites (Harvey Cedars and Tuckerton, lower graph). Note that there was no water column sampling between the two Trials, July 11 to Aug. 11.



The slope of the linear regressions fitted to the relationship between PON and Chl *a* concentrations provide a measure of the contribution of phytoplankton biomass to total particulate organic matter, including detritus (Figure 8). The IBSP site differed from the three other sites in that Chl *a* and PON were not significantly correlated (R^2 = 0.099), indicating that phytoplankton (vs. detritus) made a limited contribution to the total organic pool at this site, as was also found in 2012. The highest Chl *a*:PON ratio, measure by the slope of the linear regression, was found at the two southern sites, Tuckerton and Harvey Cedars.

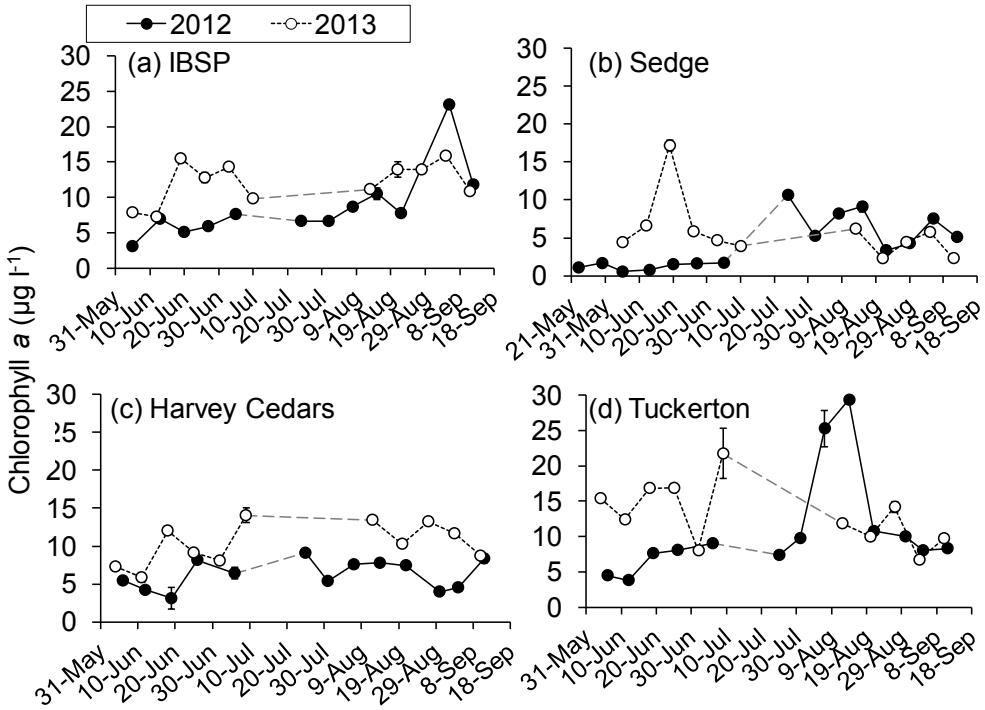
Figure 8. Relationship between particulate organic nitrogen (PON) and total Chlorophyll *a* concentrations at the four study sites. Linear regression equations fitted to the data (including Trials I and II) are shown, as well as the coefficient of determination (R^2).



Phytoplankton characterization

Phytoplankton biomass, as measured by total Chl *a* concentrations, is compared between 2012 and 2013 in Figure 9. Typically Chl *a* concentrations were lower in 2012 than 2013 at all four study sites during Trial I (June-July). This was especially evident at Sedge where Chl *a* concentrations remained below 2 µg l^{-1} throughout the early summer. The highest Chl *a* concentration (~ 30 µg l^{-1}) was measured at Tuckerton in mid-August, followed by a peak concentration of ~ 22 µg l^{-1} in IBSP in early September. Despite lower Chl *a* maxima at Tuckerton and IBSP, mean Chl *a* concentrations were generally higher in 2013 than in 2012.

Figure 9. Comparison of mean Chlorophyll *a* concentrations (± SE) in 2012 and 2013 at the four study sites (a-d). Grey dashed lines mark the period between Trials I and II, when no measurements were available.



Phytoplankton composition

The contribution of major functional taxonomic phytoplankton groups using CHEMTAX analysis is shown for Sedge and IBSP in Figure 10, the two sites where microscopic analysis of the microalgal species composition was available from split water samples. Data are also presented at the two southern sites, although validation of FTGs for the Tuckerton Cove site was only available in 2012 from phytoplankton taxonomic data determined for another NJDEP water quality monitoring site in central Little Egg Harbor (BB12, Figure 1).

In order to determine the degree of spatial variability in phytoplankton composition in relation to Toms River, phytoplankton community structure at IBSP was compared to BB05 (Figure 1) in 2012. Biovolume concentrations and class composition were similar at these two sites, except for early in the season, where diatoms biovolume at BB05 exceeded IBSP by more than an order of magnitude. Pico-coccoid biovolume concentrations were comparable at the two sites, except in July, where a peak in pico-coccoid biovolume ($1.6*10^{10}$ μm^3 l^{-1}) was observed at IBSP, but not at BB05 (not shown).

The most noteworthy result is that the phytoplankton assemblage at IBSP was distinct from the other 3 sites in that it showed a high mean contribution of cyanobacteria (28.3% averaged throughout the 2013 study period) and chlorophytes (18.0% over the 2013 study period) to total Chl *a* relative to the other sites (1.5-11.6% and 2.6-11.0% for cyanobacteria and chlorophytes, respectively), groups that are known to be indigestible and therefore support poor growth of hard clams (Bricelj et al 1984, Bass et al 1990). In contrast, the phytoplankton at Sedge Is., Tuckerton and Harvey Cedars was dominated by diatoms (mean

over the 2013 study period = 50.6-55.0%). The total Chl *a* concentration was also significantly higher at Sedge during Trial I in 2013 than in 2012 (Figures 9 and 10). A distinct peak in total Chl *a* was observed at Sedge in mid-June, concomitant with peak cell concentrations of *A. anophagefferens* detected by immunofluorescence (see below), whereas Chl *a* remained high between mid-June and mid-September at IBSP. It is likely that *A. anophagefferens* contributed significantly to the % diatom CHEMTAX estimates on this date (Figure 10), due to the common pigment fucoxanthin in these two groups. Tuckerton Cove and Harvey Cedars showed a higher mean contribution of cryptophytes (mean over the study period = 20.6 and 24.1%, respectively) than the northern study sites, where cryptophytes contributed on average only 6.2% and 10.5% at IBSP and Sedge, respectively (Figure 11). Overall, dinoflagellates made a minor contribution to the total summer phytoplankton biomass at all four study sites. Species composition of the dominant phytoplankton species determined microscopically from split samples at Sedge and IBSP is shown in Appendix I. At IBSP, the most commonly occurring species cyanobacterial species was *Aphanocapsa sp.,*and the most common diatom species was *Cyclotella choctawatchea.*

Figure 10. Contribution of phytoplankton classes (functional taxonomic groups based on photopigment analysis) to Chlorophyll *a*, as estimated by CHEMTAX. [*Aureococcus anophagefferens* was not included in the analysis shown below, but when included it made an important contribution to total Chl *a* on June 19 at Sedge, when brown tide peaked at 400 cells μl^{-1} thus confounding the estimate of the % contribution of diatoms on that date (not shown)]. The break in the horizontal axis indicates the gap between sampling periods (Trials I and II). Note the difference in vertical scales.

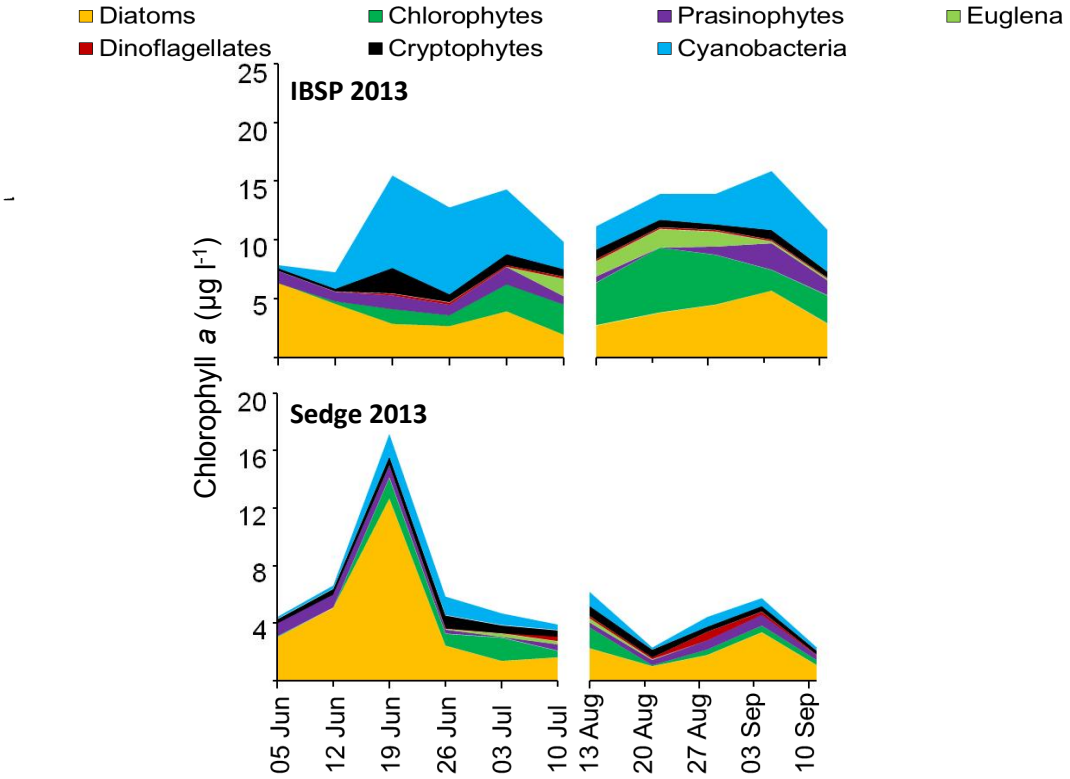
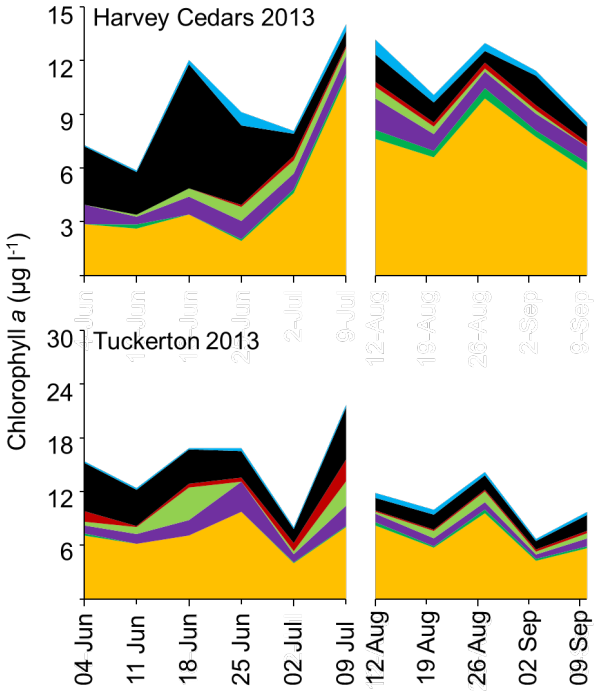


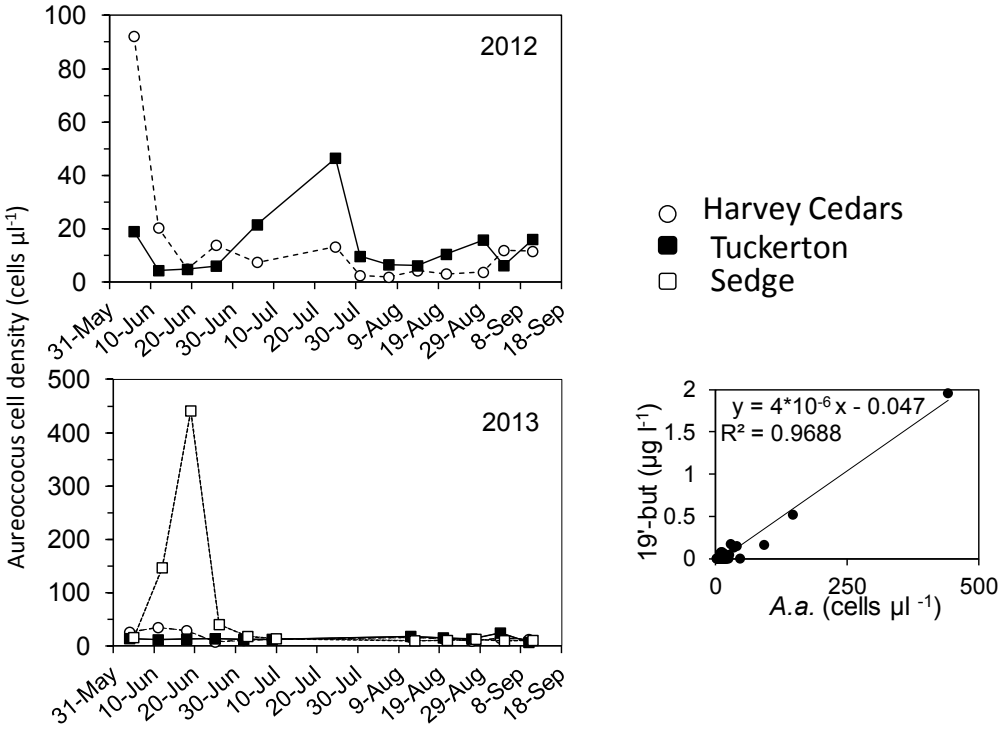
Figure 11. Contribution of phytoplankton classes (functional taxonomic groups based on photopigment analysis) to chlorophyll *a*, as estimated by CHEMTAX. The break in the horizontal axis indicates the gap between sampling periods (Trials I and II). Note the difference in vertical scales. Algal classes as in Figure 10.



Brown tide

Although outside the scope of this project, *A. anophagefferens* concentrations were determined by immunofluorescence at selected study sites in 2012 and 2013. High concentrations (up to ~440,000 cells ml^{-1}) were detected at Sedge in 2013 (Figure 12). No water samples were previously collected for determination of the presence of brown tide in the MCZ prior to this study. Furthermore, when all available data were combined (2012 and 2013), a high correlation ($R^2 = 0.9688$) was found by fitting a linear regression to the relationship between *A. anophagefferens* densities and the concentration of the diagnostic pigment 19' but.

Figure 12. *Aureococcus anophagefferens* cell concentrations, as measured by immunoflourescence, for selected sites (Harvey Cedars, Tuckerton, and Sedge) during the 2012-2013 study periods. Cell concentrations were not measured at Sedge (2012) or IBSP (both years). Inset: Linear regression of the marker pigment 19' but vs. *A. anophagefferens* cell concentration for combined 2012-2013 data.



Growth of juvenile hard clams

Overall, highly significant differences in clam growth rates (as measured by the instantaneous growth coefficient k_{DW}) were found among the four study sites and among weeks (two-way ANOVA, $p < 0.001$). The observed site-differences supported our initial selection of sites that would offer contrasting habitats representative of various sectors of BB-LEH along a north to south gradient. There was also a highly significant Week x Site interaction ($p < 0.001$). Relative weekly growth rates in soft tissues of juvenile *M. mercenaria*, k_{DW}, measured at the four study sites during Trials I and II are shown in Figures 13 and 14, and those in shell growth (kSL) are shown in Figures 19 and 20. Statistically significant differences in kDW over time were found at IBSP and Tuckerton during Trial I and among all sites during Trial II. The low growth rates at IBSP during early summer ($k_{DW} < 1\%$ day^{-1}) throughout June) are associated with low salinities occurring at this time, as reflected by high precipitation recorded at the Toms River station (Figure 15). This high-rainfall event was associated with a minimum salinity value of 16 at this site in 2013. Comparable high-precipitation events were not documented in 2012 and led to higher clam growth rates at IBSP the previous year.

Figure 13. Mean instantaneous growth coefficient, k_{DW} (± SE) of juvenile *M. mercenaria*, based on the weekly change in dry weight (DW) of soft tissues during Trial I. Results of ANOVAs and Tukey multiple comparisons are indicated.

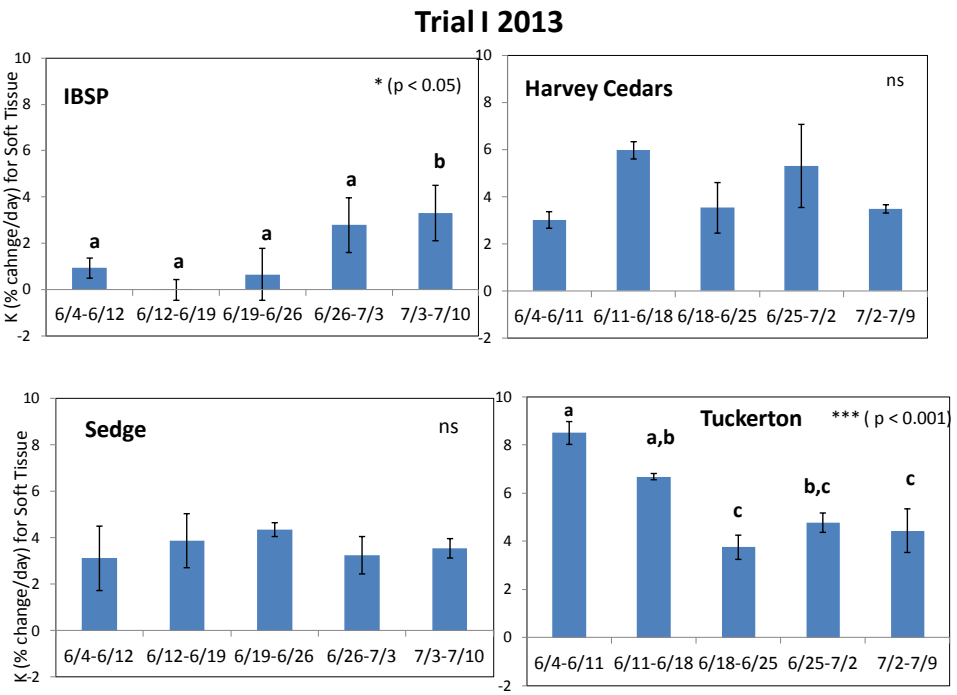


Figure 14. Mean instantaneous growth coefficient, k_{DW} (± SE), of juvenile *M. mercenaria* based on the weekly change in dry weight (DW) of soft tissues during Trial II. Results of ANOVAs and Tukey multiple comparisons are indicated.

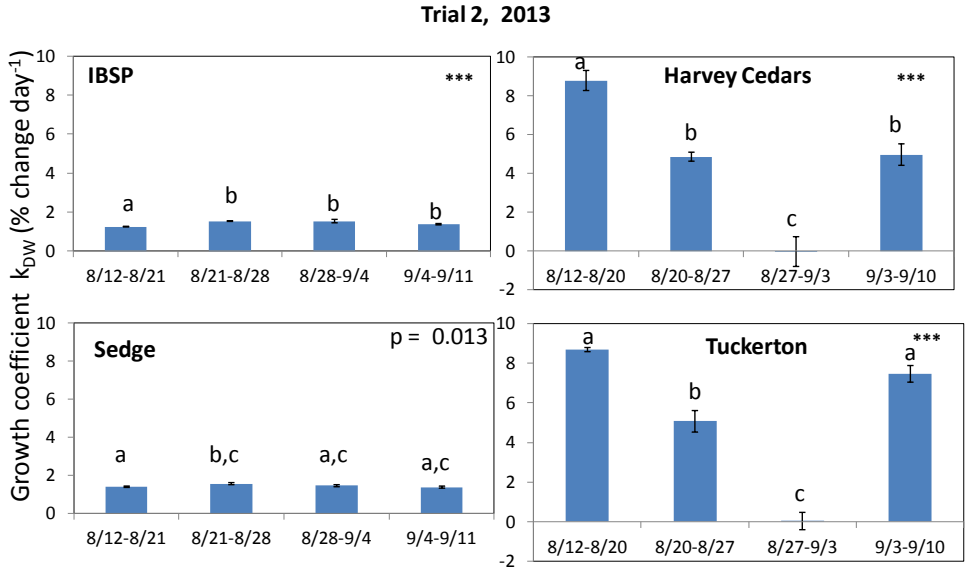
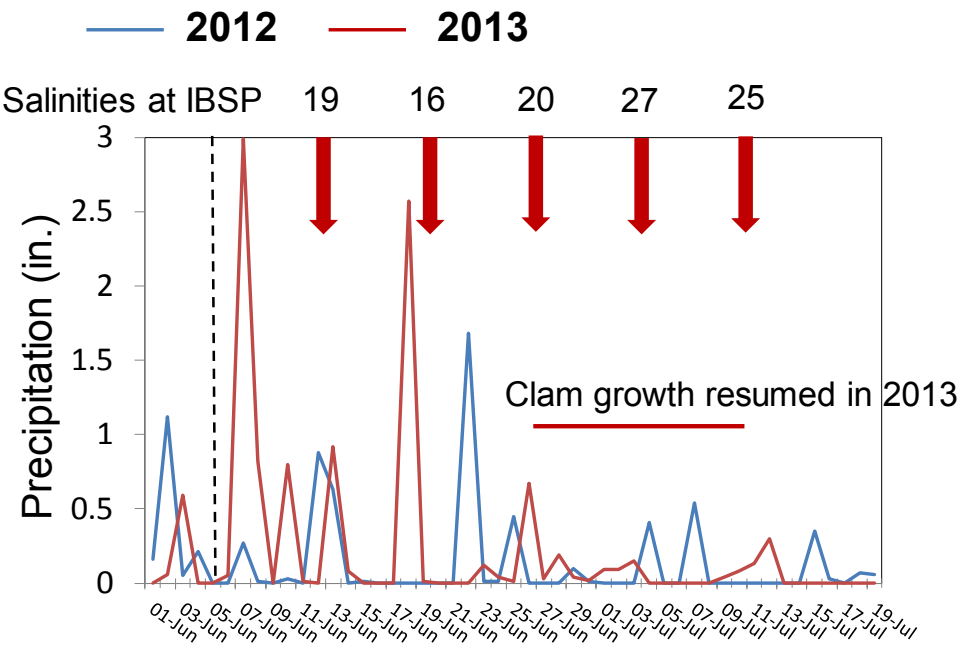


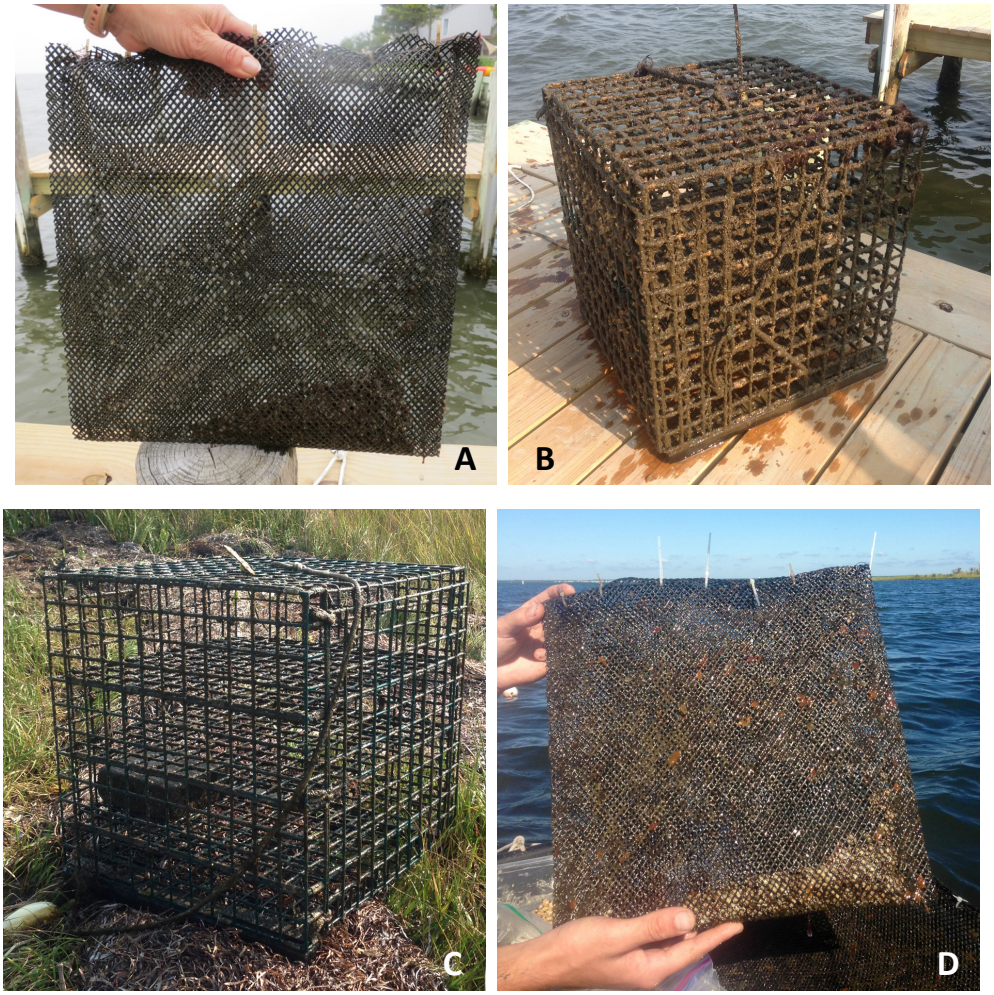
Figure 15. Precipitation at Toms River (in inches) showing unusually high rainfall events in June 2013 associated with negligible clam soft tissue growth at this site. Red arrows indicate discrete salinities measured at this site with a refractometer, that attained a minimum recorded of 16 on June 19, 2013. Dashed vertical line marks the beginning of Trial I. Comparable precipitation record shown for 2012.



Weekly clam growth rates at the Tuckerton study site were relatively high throughout the 2013 study period, except for one week (Aug, 27 to Sept. 3) during Trial II (Figure 14). Cessation of growth during this one week was clearly attributed to fouling by solitary tunicates (Figure 16). Removal of tunicates from all cages at this site resulted in immediate resumption of clam growth, and no recolonization of tunicates was observed on sampling conducted Sept. 12. Other than this event, fouling of cages or mesh bags was limited at the four sites throughout both trials and was kept in check by weekly scrubbing and removal of macroalgal, encrusting polychaetes, colonial tunicates (Botryllus spp.) or other fouling organisms (illustrated in Figure 17).

Figure 16. Documentation of heavy infestation by solitary tunicates (presumable Molgula spp.) on Sept. 3, 2013 at Tuckerton. Attachment to individual clams (left) and heavy colonization resulting in clumping of clams (right) are shown. Juvenile clams averaged 11.7 mm in shell length at this time.

Figure 17. Limited fouling of cages or mesh bags containing juvenile clams was documented during the study period, with the exception of one week of heavy tunicate infestation at Tuckerton (Figure 17). A) mesh and B) cage, respectively, from Harvey Cedars, July 9, 2013; C & D) Cage and mesh bag at Sedge Sept. 4, 2013.



Changes in weekly shell growth rate during Trial I at the four study sites are illustrated in Figure 18, allowing comparison with changes in growth of soft tissues. Differences are observed between growth patterns indicating seasonal- and site- differences in the allocation between shell and tissue growth. For example, tissue growth resumed in early July during Trial I, following the low-salinity period at IBSP, but no resumption in shell growth was detected. There was also a mismatch between tissue and shell growth patterns at Tuckerton: the highest tissue growth rates were observed from June 4 to June 18 (Figure 13), whereas low shell growth rates were determined during the 1st week of June, comparable to those determined in late June and the 1st week of July (Figure 19). Similarly, differences were observed between soft tissue and shell growth rates during Trial II. For example, tunicate infestation during week 3

resulted in complete cessation of tissue growth (Figure 14) whereas shell growth continued during this period, although at a significantly reduced rate relative to the previous week (Figure 19). Shell growth at Harvey Cedars also continued during week 3 of Trial II (Figure 14), although at a significantly reduced rate relative to the previous week, whereas shell growth ceased during week 3 of this trial (Figure 19). It is also noteworthy that at IBSP, the increase in shell growth was much greater during late-August, early September, relative to the 1st week of August than that in tissue growth.

Figure 18. Mean instantaneous growth coefficient, k_{SL} (± SE) of juvenile *M. mercenaria*, based on the weekly change in shell length (SL) during Trial I. Results of ANOVAs and Tukey multiple comparisons are indicated. The final shell length of the clams at the end of Trial I was equal to: IBSP: 8.90 mm, Sedge: 11.82, Harvey Cedars: 12.40 mm, Tuckerton: 14.07 mm.

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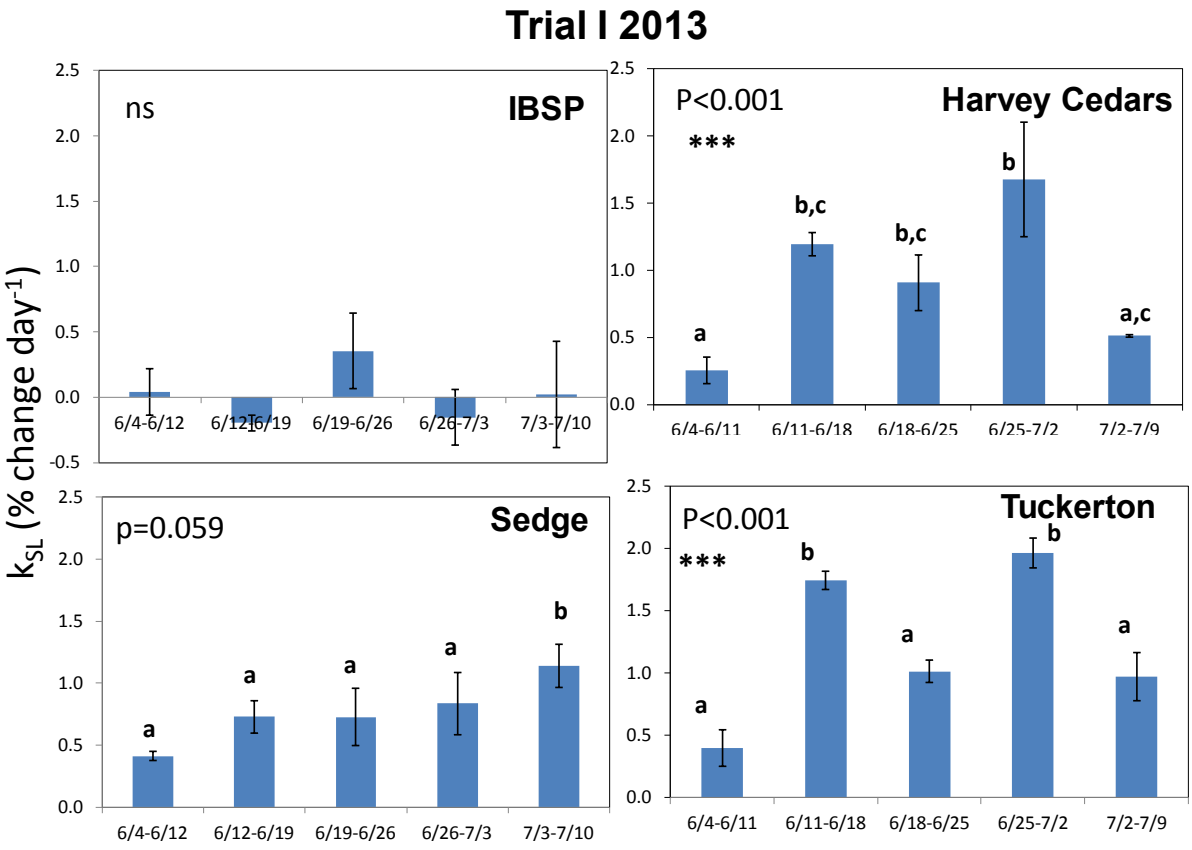
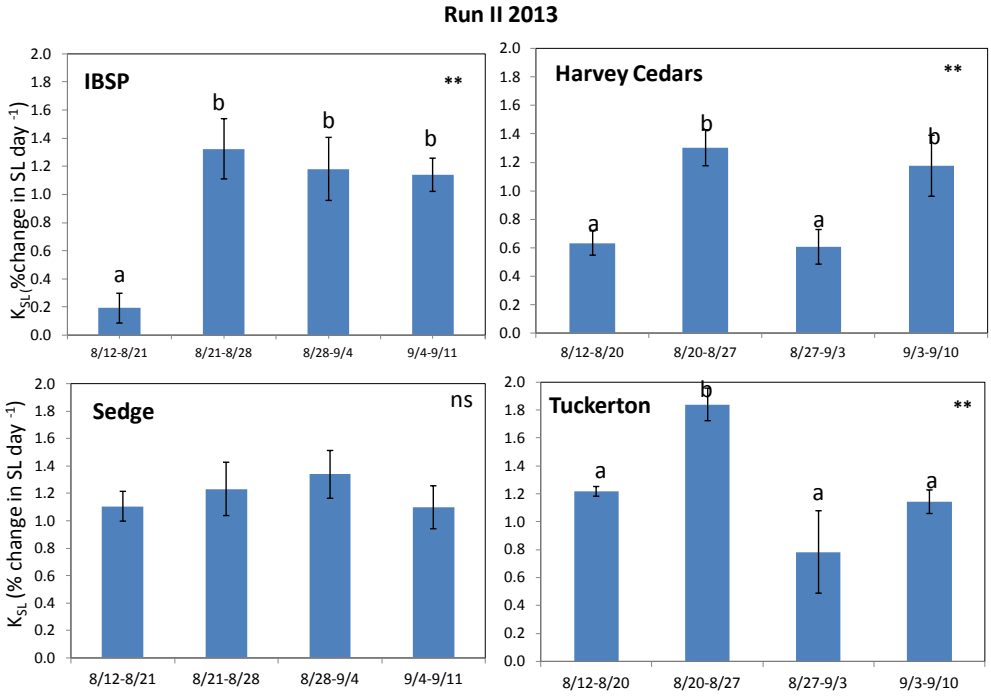


Figure 19. Mean instantaneous growth coefficient, k_{SL} (± SE) of juvenile *M. mercenaria*, based on the weekly change in shell length (SL) during Trial II. Results of ANOVAs and Tukey multiple comparisons are indicated. The final shell length of the clams at the end of Trial II was: IBSP 11.59 mm, Sedge: 12.55 mm, Harvey Cedars: 11.50 mm, Tuckerton: 12.68 mm,.



The ranking for overall, time integrated shell growth rate of juvenile clams among sites over the whole 2013 study period including Trials I and II (Figure 20) was:

Tuckerton > Harvey Cedars (HC) > Sedge >> IBSP during Trial I, and

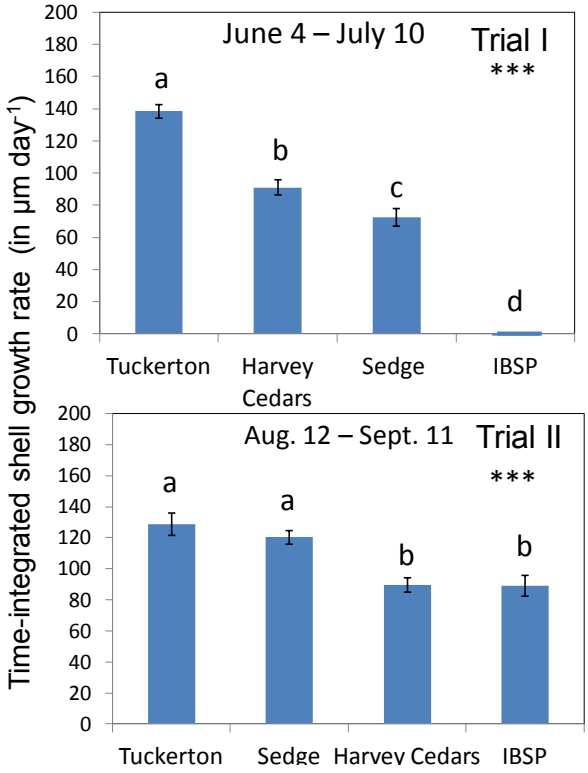
Tuckerton = Sedge > HC = IBSP during Trial II.

Clam in Tuckerton thus showed consistently higher growth rates in 2013, with a maximum attained of ~140 µm day^{-1} during the early summer, whereas growth was negligible at IBSP, the northernmost site, during Trial I, and low to moderate during Trial II.

In contrast, the ranking of clam shell growth rates during Trial II 2012, when the same (4 mm) mesh size was used to hold clams, was:

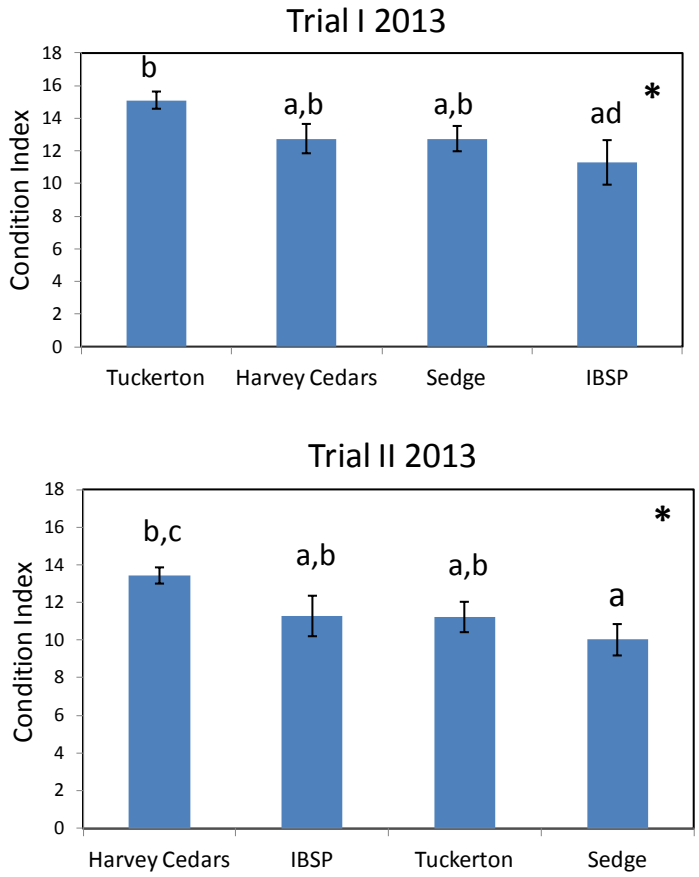
Sedge > Tuckerton = IBSP > Harvey Cedars.

Figure 20. Time-integrated, absolute shell growth rate (in µm day^{-1}) of juvenile hard clams calculated over the whole trial period for Trials I and II.



The condition index (CI) of juvenile clams was lower at the time of deployment in both trials (8.93 and 7.76 for Trials I and II, respectively) than at the end of each trial. In Trial I the lowest condition was determined at IBSP, although it only differed significantly ($p < 0.05$) from that at Tuckerton, the site with highest overall shell growth rates (Figure 21). In Trial II the lowest condition was determined at Sedge, where it differed significantly only from that at Harvey Cedars. Thus, while the highest overall growth rate was also associated with the highest condition in Trial I, a mis-match between condition and growth rates was observed in Trial II. The maximum CI attained in 2013 was 16.65 at Tuckerton at the end of Trial I, on July 10.

Figure 21. Condition index (CI = soft tissue DW/SL^3) of juvenile hard clams, time-averaged over each trial. Different letters above each bar indicate significantly different CI between sites (ANOVA, Tukey multiple comparisons, $p < 0.05$). The initial CI of deployed clams was equal to 8.93 ± SE = 0.19 (n = 50 clams), and 7.76 ± 0.13 (n = 50), in Trials I and II, respectively.



Clam mortalities

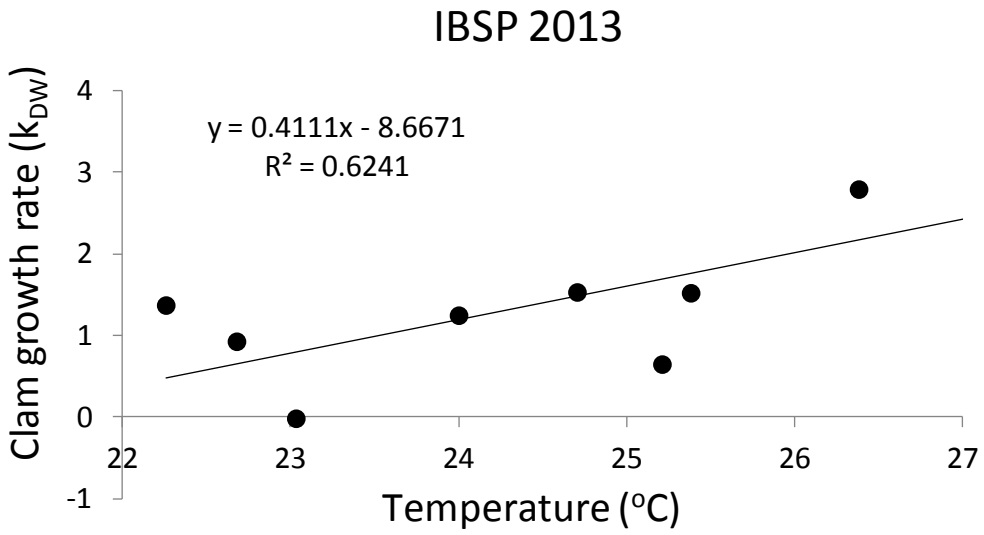
Cumulative mortalities of juvenile clams were generally higher during Trial II than Trial I 2013 (Table 2), as was also found in 2012. This likely reflects the fact that for Trial I seed clams produced by the commercial hatchery were overwintered prior to their use in field experiments. Seed from the 2013 production are generally too small by the time needed for June deployment in 4 mm mesh bags. Mortalities during Trial II were negligible, attaining a cumulative value <3% across all study sites (Table 2). During Trial I a relatively high mortality event (maximum cumulative mortality = 42%) was documented on June 18. Mortalities at the two southern sites were the lowest, remaining below 13%. Cumulative mortalities were typically observed to decline over time. This is an artifact attributed to the breakage and loss of small shells over time within the cages.

Table 2. Mean percent cumulative mortalities of juvenile clams (± standard deviation, SD, n = 3 cages) during the 2013 study period. Maximum mortalities are highlighted in grey. The initial mortality for Trial I was based on a mean of in situ measurements based on empty shells (mean = 9.58%; n = 1994 clams) and a follow-up mean measurement in the laboratory based on dissection of clams (mean = 7.41%, n = 108 clams). Mean of means = 8.49% (SE = 1.09).

Trial I	Tuckerton		Harvey Cedars		Sedge		IBSP	
Date	Mean	SD	Mean	SD	Mean	SD	Mean	SD
June 11/12	17.71	4.996	11.05	14.783	38.88	21.232	5.96	4.44
June 18/19	15.32	12.620	13.19	5.825	41.54	10.886	18.01	5.257
June 25/26	6.62	6.708	5.90	2.990	33.54	14.882	8.48	4.139
July 2/3	2.18	6.042	4.17	4.709	37.81	8.295	7.05	5.208
July 9/10	2.34	4.428	7.67	4.215	29.51	2.911	11.23	2.448
Trial II	**Tuckerton**		**Harvey Cedars**		**Sedge**		**IBSP**	
Date	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
August 20/21	ND	ND	0.41	0.820	1.35	1.676	0.28	0.477
August 27/28	0.00	0.000	0.41	0.820	0.00	0.000	0.55	0.946
Sept. 3/4	0.00	0.000	0.41	0.820	1.86	2.544	0.00	0.000
Sept. 10/11	0.00	0.000	0.12	0.249	0.17	0.287	0.50	0.495

At IBSP, a significant ($R^2 = 0.6241$, $p = 0.011$) positive relationship between k_{DW} and temperature was determined in 2013 (Figure 22). It is likely, however, that this is an artifact of low temperatures early in the season, when growth ceased (Figure 17) during a low salinity event (Figure 4b). The relationship between temperature and k_{DW} was not statistically significant at any of the other sites in 2013.

Figure 22. Relationship between clam growth and temperature at IBSP during Trial I 2013.



Fewer significant relationships were observed between k_{DW} and phytoplankton composition derived from CHEMTAX results in 2013 than in 2012 (Table 3). This is likely due to less variability in total and FTG-specific Chl *a* concentrations in 2013, especially at IBSP and Tuckerton. Significant positive relationships were observed, however, between measures of diatom abundance (% diatom contribution to Chl *a* and fucoxanthin concentration) and total Chl *a* at Sedge (Table 3), despite the likelihood that *A.*

anophagefferens contributed a large fraction of Chl *a* and fucoxanthin during the period of greatest soft tissue growth during Trial I (Figure 13). Measurements of k_{DW} may have been skewed early during Trial I, if mortalities were size-specific (Table 2), and results may also have been affected by high variability in k_{DW} among cages during weeks 1 and 2 (Mean ± SE = 3.121 ± 1.381 and 3.876 ± 1.177 in week 1 and week 2, respectively, Figure 13) (see Discussion)..

Table 3. Results from linear regressions of juvenile clam growth coefficients based on soft tissue dry weight (k_{DW}) vs. CHEMTAX results (µg chl *a* l^{-1} by class) and diagnostic photopigments (µg pigment l^{-1}). Equations are of the form y = bx+a, where y = k_{DW}, b = slope, x = photopigment parameter. Results are shown only for parameters with significant relationships for at least one site/sampling year. * = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$; † = considered marginally significant ($p \leq 0.08$).

IBSP	**2012**			**2013**			**Combined**		
FTG Parameter	R2	Slope	Sig.	R2	Slope	Sig.	R2	Slope	Sig.
Cyanobacteria	0.3028	-2.290	†	0.0045	+0.0325		0.0757	-0.3557	
Zea	0.4317	-3.418	*	0.0127	+0.0701		0.0869	-0.4901	
Picoplankton	0.3188	-0.9977	†	0.0661	+0.1179		0.1305	-0.3814	
% Picoplankton	0.3765	-0.1167	*	0.1167	+0.0242		0.1003	-0.0492	
Sedge Island	**2012**			**2013**			**Combined**		
FTG Parameter	R^2	Slope	Sig.	R^2	Slope	Sig.	R^2	Slope	Sig.
Diatoms	0.1774	+0.2762		0.4686	+0.2949	*	0.1784	+0.2548	†
% Diatoms	0.2901	+0.0504	†	0.1357	+0.0297		0.2175	+0.0455	*
Fuco	0.1722	+0.5543		0.4954	+0.4635	*	0.1145	+0.3396	
% Cyanobacteria	0.3793	-0.2499	*	0.0124	+0.0276		0.1839	-0.1380	
Zea/Chl *a*	0.4124	-35.9128	*	0.0334	+6.1830		0.1722	-18.3210	
Chl-b/Chl *a*	0.3080	-12.9473	†	0.1832	-18.6030		0.1403	-10.6996	
Chl *a*	0.1080	+0.1789		0.5511	+0.2779	*	0.1029	+0.1600	
Harvey Cedars	**2012**			**2013**			**Combined**		
FTG Parameter	R^2	Slope	Sig.	R^2	Slope	Sig.	R^2	Slope	Sig.
Diatoms	0.4062	1.0131	*	0.0207	-0.1286		0.1393	+0.4561	
Fuco	0.3433	1.8324	*	0.1242	-0.1994		0.1772	+0.9430	
Zea/Chl *a*	0.2902	-230.4430	†	0.1850	+94.7540		0.0455	+65.0690	
Chl *a*	0.4588	1.3255	*	0.0016	-0.0521		0.3089	+0.6033	*
Tuckerton	**2012**			**2013**			**Combined**		
FTG Parameter	R^2	Slope	Sig.	R^2	Slope	Sig.	R^2	Slope	Sig.
Diatoms	0.3208	+0.1667	†	0.1913	-0.8148		0.0669	+0.1582	
% Diatoms	0.5161	+0.0763	*	0.0984	+0.0760		0.2283	+0.0972	*
Fuco	0.3965	+0.4054	*	0.0607	+0.6059		0.2225	+0.6043	*
Fuco/Chl *a*	0.5426	+14.319	**	0.4218	+15.8682	†	0.5003	+21.2750	***
% Cyanobacteria	0.2937	-179.109	†	0.1179	+45.6910		0.2322	+103.9294	*
Zea/Chl *a*	0.3184	-164.274	†	0.1079	+59.0790		0.1064	-96.3350	
Chl-b/Chl *a*	0.4279	-16.8160	*	0.1817	-19.6920		0.2653	-23.978	*
Chl *a*	0.2557	+0.1197	†	0.2886	-0.38460		0.0627	0.1177	

Discussion and Conclusions

A characteristic, summer-early fall phytoplankton assemblage was found at the two northern study sites, IBSP and Sedge, relative to Tuckerton and Harvey Cedars, with IBSP showing a high

contribution of cyanobacteria to total algal biomass. These differences were maintained over the two consecutive study years despite the impact of Superstorm Sandy in October 2012. Differences among sites in physical parameters (temperature and salinity) were also relatively consistent between 2012 and 2013, pre-and post-Sandy years, respectively. There is thus no evidence that Superstorm Sandy exerted major effects on phytoplankton communities or juvenile hard clam production by the summer following its impact on the BB-LEH estuary, although changes may have occurred during the winter-spring of 2013, a period not covered by the present study.

Despite fairly consistent characteristics in phytoplankton composition between sites over the two years, some inter-annual differences were observed at each site. Mean Chl *a* concentration was greater at all sites in 2013 (Figure 9), although the difference was only significant at Harvey Cedars. At Sedge, the Chl *a* maximum in 2013 corresponded with maximum *A. anophagefferens* densities. At IBSP, where cyanobacteria were a prominent constituent of the algal assemblage, the maximum concentration of cyanobacterial Chl *a* increased from 4.4 μg l^{-1} in 2012 to 7.4 μg l^{-1} in 2013, although the mean % contribution of this class remained comparable between years. At both southern sites, Harvey Cedars and Tuckerton, the maximal % contribution of cryptophytesto total Chl *a* occurred in early summer in both years, (= 71.3% and 57.6%, in 2012 and 2013, respectively, at HC, and 34.9% and 35.1% in 2012 and 2013, respectively, at Tuckerton) (Figure 11).

Small forms (< 5 μm diameter; ~ 65 μm^3 biovolume) contributed a high % of the microalgal biovolume at IBSP in both years (45% in 2012 and 67% in 2013). At Sedge the mean contribution of small forms was significantly higher in 2013 than 2012 (47% vs. 7%) (Appendix I).

There was significant spatial and temporal variability in juvenile clam growth rates in BB-LEH. Clams at Tuckerton showed the highest (3 out of 4 trials throughout the combined 2012 and 2013 study) or 2nd highest overall shell growth rates (in μm day^{-1}). Although seston concentrations were higher at this site, highest PIM levels remained ≤ 26 mg L^{-1}, i.e. the threshold level that is known to inhibit growth of juvenile *M. mercenaria* in controlled laboratory experiments (Bricelj and Malouf, 1984). Maximum weekly shell growth rates in the BB-LEH were 175 & 144 μm day^{-1}, in 2012 and 2013, respectively, approaching but not attaining maxima reported in other mid-Atlantic estuaries (~ 200 μm day^{-1}) (reviewed by Grizzle et al 2001).

Clam growth rates at Sedge were generally higher than at IBSP despite consistently lower daily temperatures, high early summer temperature fluctuations & lower Chl *a* levels at Sedge. This is attributed to the high food quality at this site (high diatom contribution) relative to IBSP. The Sedge Is. study site was characterized by extremely high daily temperature fluctuations, especially during early summer (up to 10^oC and 16^oC day^{-1} in 2012 and 2013, respectively). The effects of these on growth and survival of hard clam larvae and juveniles, as well as reproduction, remain to be determined.

Lower clam growth rates at IBSP are attributed to early summer low salinity events that may result in transient salinities below the tolerance range for hard clam growth. Relatively low clam growth rates at IBSP are also attributed to poor food quality despite consistently higher % POM & PON, and high Chl *a* concentrations at this site. This is reflected in the high % contribution of (cyanobacteria + chlorophytes)/Chl *a*, and high detrital contribution (low Chl *a*/PON) at IBSP. The low salinities and high contribution of cyanobacteria at IBSP are associated with the influence of the Toms River plume, a major freshwater source to the BB-LEH estuary and high dissolved nitrogen input to this ecosystem in the upper reaches of Barnegat Bay (Kennish and Fertig 2012).

The present study provides clear evidence of mis-match between weekly patterns of soft tissue and shell clam growth, indicating differences in the allocation of energy to these two processes. As might be expected, soft tissue growth is more markedly and immediately affected by changes in environmental conditions and thus provides a more sensitive index of short-term environmental change.

Microalgal photopigment analysis by HPLC provided a powerful tool to characterize the contribution of various phytoplankton taxonomic groups to total phytoplankton biomass in the BB-LEH. This method is less labor-intensive and less costly than microscopic analysis, but must be validated by microscopic analysis to allow reliable characterization of spatial and temporal changes in the phytoplankton assemblage. The FTG method may, however, allow a reduction in the spatial and temporal scale of water column sampling and thus help to provide more synoptic analysis of the phytoplankton within this large estuary. Our study provides the first application of FTG analysis to determine seasonal succession and site-specific characterization of the phytoplankton in this estuary. Results of this study also showed that the presence of high concentrations of *A. anophagefferens* ($\geq 10^2$ cells μl^{-1}) may confound results of FTG analysis by CHEMTAX, given that *A. anophagefferens* contains relatively high levels of fucoxanthin, a pigment typically used as diagnostic of diatoms. Overall, there was generally a good correlation between the contribution of dominant FTGs and biovolume of phytoplankton estimated from microscopic analysis. Some uncertainty was introduced, however, by the fact that pico-coccoids, which at times made an important contribution to phytoplankton biomass, likely represented a mixture of cyanobacteria, chlorophytes and brown tide cells, that were not distinguished microscopically.

Total Chlorophyll *a* concentrations at the four study sites remained below ~25-28 $\mu g\ l^{-1}$ during the summer-early fall of both 2012 and 2013, and were thus generally not indicative of eutrophic conditions in this estuary. The maximum Chl *a* concentration attained (30 $\mu g\ l^{-1}$) was measured at Tuckerton where highest overall clam growth rates were recorded in our 2013 study. A significant correlation between juvenile clam growth and Chl *a* concentrations, however, was only observed at Sedge Is. where Chl *a* levels were typically lower than at the other 3 study sites.

Phytoplankton compositional changes were generally considered a more important determinant of juvenile clam growth than total phytoplankton biomass (or temperature) throughout this study.

Results of photopigment analysis, confirmed by species-specific immunofluorescence, demonstrated that the brown tide alga, *Aureococcus anophagefferens*, was present in the BB-LEH ecosystem during 2012 and 2013 at levels that, based on laboratory (Bricelj et al. 2004) and field studies in other mid-Atlantic coastal lagoons (Wazniak and Glibert 2004), can inhibit production of hard clam larvae and juveniles. Surprisingly, the highest concentration measured, ~ 440 cells μl^{-1}, was measured at Sedge Is., within the MCZ, an area highly influenced by oceanic exchange via the Barnegat Bay Inlet, rather than in southern portions of the bay where *A. anophagefferens* was historically found to attain highest concentrations. Yet, *A. anophagefferens* (Pelagophyceae) is considered a picoplankter of oceanic origin, and the present study provides the first confirmation of brown tide within the MCZ, as previous studies conducted in the 1990s did not collect samples within this body of water. The concentration of the pigment 19'but and the concentration of *A. anophagefferens* determined by immunofluorescence, when 2012 and 2013 data were combined at all sites, were highly correlated. Using the methods described in the present study (seawater volumes filtered through 2.5 mm diameter filters, results indicate that 19' but was able to detect a minimum density of ~ 30 cells *A. anophagefferens* μl^{-1}, approximately the threshold density determined in laboratory experiments that needs to be exceeded to inhibit clearance rates of juvenile hard clams (Bricelj et al. 2004). It is likely that a even lower limit of detection would be possible by filtering larger volumes through larger filters. No significant reduction in the growth of clams could be related to the concentration of *A. anophagefferens* at sites where the former was detected. This may be due to the fact that the time-series for brown tide analysis was limited, that the documented high densities were relatively transient, and/or may be related to low toxicity of brown tide cells.

Clam mortalities during the 2013 study period were generally low except for an unexplained high-mortality incident documented in early June at Sedge. It is noteworthy that the high, unexplained mortalities documented at Sedge at the beginning of Trial I (39 to 42%, Table 2) coincided with the highest concentrations of *A. anophagefferens* (100 to 400 cells μl^{-1}) at this site. Yet it is unlikely that brown tide was the cause, as laboratory studies have shown exposure to bloom levels of *A. anophagefferens* (up to 1,000 cells μl^{-1} over a few weeks) resulted in starvation and growth cessation but did not induce mortalities of juvenile hard clams of comparable size (Bricelj et al. 2004). Field studies in Great South Bay, NY (Greenfield and Lonsdale 2002), however, have shown high mortality rates in juvenile hard clams (~30% over two weeks and ~60% over 3 weeks) coincident with *A. anophagefferens* blooms, although brown tide levels were up to an order of magnitude higher ($1.5x10^6$ cells ml^{-1}) during their study, and juvenile hard clams were smaller (2-3 mm) and thus likely more vulnerable than in the present study. Therefore, the causes of these high mortalities of clams at Sedge immediately following deployment remain speculative and may also reflect specific conditions at this site at the time of cage deployment, e,g, intrusion of cold waters via

Barnegat Inlet at the time of planting given that this site is subject to high fluctuations in temperature over hourly time scales, or a combination of the factors mentioned above.

Overall, this study indicates that environmental conditions during the summer-early fall at four representative sites in BB-LEH can support moderate growth rates of juvenile *M. mercenaria*, although growth rates were highly variable on a weekly basis (Figures 13, 14, 18 and 19).

Dissemination of information

Conference presentations:
Results of this study were presented at the March 2014 National Shellfisheries Association meeting, Jacksonville, FL: V.M. Bricelj, R. Fantasia, L. Izzo, C. Noji, J.N. Kraeuter, G. Flimlin. "Relationship between hard clam, *Mercenaria mercenaria*, growth and the food supply in Barnegat Bay, a mid-Atlantic coastal lagoonal ecosystem",

Dec. 2014, Barnegat Bay Workshop, NJDEP, Bordentown, NJ: V.M. Bricelj, R. Fantasia, Carola Noji, E. McGurk, Gef Flimlin, J. Kraeuter: "Growth and reproduction of hard clams*, Mercenaria mercenaria*, in relation to environmental conditions in Barnegat Bay, a NJ coastal lagoonal ecosystem", and

Oct. 2014, Ocean County Extension office, Toms River, NJ. V. M. Bricelj, J. Kraeuter, G. Flimlin, R. Fantasia, C. Noji. "Growth and reproduction of hard clams*, Mercenaria mercenaria*, in relation to environmental conditions in Barnegat Bay".

Publication in preparation:

Fantasia, R., V.M. Bricelj, L. Ren. "Phytoplankton community structure using photopigment markers in a mid-Atlantic coastal lagoonal estuary, USA: significance for hard clam production". For submission to Mar. Ecol. Prog. Ser.

Acknowledgements

We thank Carola Noji, DMCS/RU, for technical support, and Conor MacDonnell, undergraduate student at the College of William and Mary, Virginia, who participated in all aspects of this study as a summer intern enrolled in the NSF-funded RIOS program at DMCS. We especially thank Ryan Fantasia for his contribution to preparation of this report, and his key role in the phytoplankton analysis. We also thank Lisa Izzo for comparative analysis of 2012 and 2013 data, Romi Patel, undergraduate work-study at IMCS for processing of clams and assistance in data workup, and Shaila Huq, undergraduate student at IMCS supported by Kay Bidle, for occasional participation in field sampling. Jeffrey Silady, Re Clam The Bay, provided boat access to Sedge Island and his unfailing support and good humor during our project activities. Ling Ren from the Philadelphia Academy of Sciences at Drexel, PA, conducted the microscopically determined taxonomic analysis of phytoplankton. We also thank Jim Merritt at the Sedge Island Fish & Wildlife National Resource Education Center, Marine Conservation Zone, for his assistance during early phases of the project,

Larry Murphy for providing access to his property in Harvey Cedars, and the IBSP Forked Interpretive Center for providing space at their facility and access to the Park for in situ processing of water samples.

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Appendix I. Water column cell density (in cells l^{-1}), cell biovolume (in μm^3 $cell^{-1}$) and cell biovolume concentration (in μm^3 l^{-1}) of phytoplankton species at the Sedge Is. and Island Beach State Park (IBSP) study sites in Barnegat Bay in summer 2013 (taxonomic identification of algal species provided by Ling Ren, Philadelphia Academy of Sciences at Drexel).

Island Beach State Park Water Column Cell Density 2013									
	Cell Volume μm^3 $cell^{-1}$	**Cell Density cells l^{-1}**							
Bacillariophyceae		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Arcocellulus G.R. Hasle, H.A.von Stosch & E.E.Syvertsen	32					1.37E+06		9.10E+05	
Asterionellopsis glacialis (Castracane) Round	187								
Cerataulina pelagica (Cleve) Hendey	5173	3.07E+06							
Chaetoceros affinis Lauder	1073								
Chaetoceros decipiens Cleve	282								
Chaetoceros simplex Ostenfeld	121					9.10E+04			
Chaetoceros sp.	169	6.83E+05			3.41E+05				
Chaetoceros subtilis Cleve	85	1.14E+06	9.10E+05	1.82E+05					
Chaetoceros subtilis var. abnormis fo. simplex	146	1.14E+05							
Chaetoceros tenuissimus Meunier	85					2.73E+05			
Cocconeis spp.	327		1.44E+04						
Coscinodiscus concinnus Smith	803840						4.00E+02		
Cyclotella atomus Hustedt	40								
Cyclotella choctawhatcheeana Prasad	153	1.71E+06	2.79E+06	4.08E+06	2.45E+06	1.32E+06	1.48E+06	9.01E+06	1.97E+07

Bacillariophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Cyclotella striata (Kützing) Grunow	521					9.10E+04			
Cylindrotheca closterium (Ehrenberg) Reimann et Lewin	317		1.44E+04		6.22E+03	5.77E+04	2.16E+04	1.44E+04	8.13E+05
Dactyliosolen fragilissimus (Bergon) Hasle	1356	3.61E+05							
Diatom Pennate_UNO	450								
Ditylum brightwellii (West) Grunow	15875	6.01E+04							
Entomoneis alata Ehrenberg	11304							7.22E+03	
Guinardia flaccida (Castracane) Peragallo	51286	3.01E+04							
Guinardia striata (Stolterfoth) Hasle	35325								
Leptocylindrus danicus Cleve	490						4.33E+04		
Leptocylindrus minimus Gran	162								
Melosira nummuloides C.Agardh	22899								
Minutocellus scriptus Hasle, von Stosch & Syvertsen	25			4.55E+05		2.89E+04	1.02E+06	8.65E+05	2.50E+06
Navicula spp.	600					4.33E+04	1.44E+04		
Nitzchia longissima (Brebisson) Ralfs	560	1.50E+05	4.33E+04						
Nitzschia spp.	360			1.95E+06			5.69E+04		
Odontella aurita (Lyngbye) Agardh	34194								
Phaeodactylum (?) tricornutum Bohlin	23	1.33E+06	3.70E+06	1.74E+07	1.07E+07	1.37E+06	1.68E+07	2.91E+07	1.53E+07
Pleurosigma salinarum (Grunow) Grunow	14130	8.00E+02		4.00E+02				2.00E+02	

Bacillariophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Pseudo-nitzschia delicatissima (Cleve) Heiden	430								4.33E+04
Pseudo-nitzschia seriata (Cleve) Peragallo	596								
Rhizosolenia imbricata Brightwell	11052	1.20E+03							
Skeletonema costatum (Greville) Cleve	243	9.10E+05							
Skeletonema menzelii Guillard, Carpenter et Reimann	48								
Thalassionema nitzschioides (Grunow) Mereschkowsky	800	2.40E+03					3.61E+04	5.05E+04	
Thalassiosira proschkinae Makarova	39	1.90E+06	2.84E+06		1.14E+05	5.69E+06	5.69E+04		
Thalassiosira tenera Prochkina-Lavrenko	3140					1.44E+04			
Bacillariophyceae (total)		1.14E+07	1.03E+07	2.40E+07	1.36E+07	1.03E+07	1.95E+07	3.99E+07	3.84E+07
Chlorophyceae									
Chlamydomonas coccoides Butcher	126	3.79E+05							
Chlamydomonas Ehrenberg (sp.)	865								
Stigeoclonium sp.	2031		3.18E+05						
Chlorophyceae (total)		3.79E+05	3.18E+05						
Chrysophyceae									
Calycomonas ovalis Wulff	28	8.99E+06	6.48E+06	8.39E+06	2.69E+07	7.24E+06	9.10E+05	4.55E+05	1.71E+06
Pseudopedinella pyriformis Carter	113	3.79E+05							

Chrysophyceae (total)		9.37E+06	6.48E+06	8.39E+06	2.69E+07	7.24E+06	9.10E+05	4.55E+05	1.71E+06
Cryptophyceae									
Hemiselmis virescens Droop	15		2.10E+06	1.63E+06	1.71E+06			1.37E+05	
Leucocryptos marina (Braarud) Butcher	69			9.10E+04	8.53E+05	2.28E+05			
Plagioselmis (Butcher) Hill (sp.)	33	1.90E+05	2.28E+05						
Rhodomonas salina (Wislouch) Hill	184		5.69E+05						
Teleaulax acuta (Butcher) Hill	131	1.14E+05				1.82E+05			
Cryptophyceae (total)		3.03E+05	2.90E+06	1.72E+06	2.57E+06	4.10E+05		1.37E+05	
Cyanophyceae									
Aphanocapsa Naegeli (sp.)	0.57	1.66E+08	1.83E+07	6.20E+07	4.95E+06	4.14E+05	3.25E+06	3.49E+04	2.62E+05
Dinophyceae									
Ceratium lineatum (Ehrenberg) Cleve	51000						2.00E+02		4.00E+02
Dinophysis acuminata Claparede et Lachmann	12505	8.00E+02							
Gymnodinium gracilentum P.H. Campbell	295			4.84E+05	2.84E+05				
Gymnodinium Stein (spp.)	365	3.01E+04	1.44E+04		1.14E+05				
Gyrodinium estuariale Hullburt	544	2.28E+05	4.55E+05		3.41E+05		1.14E+05		
Gyrodinium flagellare Schiller	157	1.14E+05	4.55E+05			1.82E+05		4.55E+04	
Heterocapsa triquetra (Ehrenberg) Stein	1789							7.22E+03	1.90E+05
Prorocentrum micans Ehrenberg	27632								

Dinophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Prorocentrum triestinum Schiller	732				2.00E+02				1.44E+04
Protoperidinium Bergh (spp.)	21993								
Scrippsiella trochoidea (Stein) Loeblich III	6133								
Dinophyceae (total)		3.72E+05	9.25E+05	4.84E+05	7.40E+05	1.82E+05	1.14E+05	5.27E+04	2.04E+05
Prasinophyceae									
Mamiella gilva (Parke et Rayns) Moestrup	65								
Pachysphaera marshalliae Parke	221			1.07E+06	4.55E+05				
Pseudoscourfieldia marina (Throndsen) Manton	12	7.58E+05	8.53E+05	9.10E+04	4.55E+05		5.69E+04		
Pyramimonas parkeae Norris & Pearson	785		5.69E+05	9.10E+04				2.73E+05	8.34E+05
Tetraselmis spp.	540				5.12E+05				1.90E+05
Prasinophyceae (total)		7.58E+05	1.42E+06	1.25E+06	1.42E+06		5.69E+04	2.73E+05	1.02E+06
Raphidophyceae									
Heterosigma akashiwo (Hada) Hada ex Hara et Chihara	508	1.90E+05							
Autotrophic Ciliates									
Mesodinium rubrum Leegaard	14360				1.24E+04				
Un-categorized									
Phytoflagellates	65			6.50E+05		9.10E+04			
Pico-coccoids (2-3 µm)	28	6.89E+07	2.28E+07	7.47E+07	2.66E+08	3.72E+08	3.08E+08	2.61E+08	1.35E+08

Sedge Island Water Column Cell Density 2013									
	Cell Volume μm^3 $cell^{-1}$	**Cell Density cells l^{-1}**							
Bacillariophyceae		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Arcocellulus G.R. Hasle, H.A.von Stosch & E.E.Syvertsen	32			4.27E+05	1.82E+05	1.82E+05	3.79E+04	3.49E+05	2.28E+05
Asterionellopsis glacialis (Castracane) Round	187				1.44E+05			1.00E+06	
Cerataulina pelagica (Cleve) Hendey	5173	1.20E+03	2.89E+04	8.00E+02	5.77E+04		8.02E+03		1.06E+05
Chaetoceros affinis Lauder	1073					5.77E+04			
Chaetoceros decipiens Cleve	282							1.37E+05	
Chaetoceros simplex Ostenfeld	121	9.10E+04		1.29E+04				1.44E+04	
Chaetoceros sp.	169		7.28E+05		1.73E+05		6.00E+02		
Chaetoceros subtilis Cleve	85	9.10E+04				9.10E+04			
Chaetoceros subtilis var. abnormis fo. Simplex	146		9.10E+04		9.10E+04				
Chaetoceros tenuissimus Meunier	85	2.40E+03				1.82E+05	4.55E+04	5.46E+05	
Cocconeis spp.	327	1.52E+05			1.44E+04			4.55E+04	
Coscinodiscus concinnus Smith	803840			2.00E+02	8.00E+02				
Cyclotella atomus Hustedt	40	5.37E+06	4.55E+06						
Cyclotella choctawhatcheeana Prasad	153		1.00E+06	3.49E+06	1.18E+06	5.22E+06	6.45E+05	3.22E+06	7.33E+06
Cyclotella striata (Kützing) Grunow	521				7.22E+04	2.31E+05		1.44E+04	9.10E+04
Cylindrotheca closterium (Ehrenberg) Reimann et Lewin	317	1.44E+04	2.89E+04		1.44E+04	1.92E+05	7.22E+03	9.03E+04	1.35E+05

Bacillariophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Dactyliosolen fragilissimus (Bergon) Hasle	1356								1.37E+05
Diatom Pennate_UNO	450	4.55E+05		1.42E+05			3.79E+04		
Ditylum brightwellii (West) Grunow	15875								
Entomoneis alata Ehrenberg	11304								
Guinardia flaccida (Castracane) Peragallo	51286								
Guinardia striata (Stolterfoth) Hasle	35325		8.00E+02						
Leptocylindrus danicus Cleve	490				6.37E+05				
Leptocylindrus minimus Gran	162					1.88E+05	7.58E+04		2.24E+05
Melosira nummuloides C.Agardh	22899			5.15E+04					
Minutocellus scriptus Hasle, von Stosch & Syvertsen	25		1.39E+06	9.56E+05	9.10E+04	1.03E+06	9.33E+05	1.85E+06	5.26E+06
Navicula spp.	600		1.44E+04				1.44E+04		
Nitzchia longissima (Brebisson) Ralfs	560								
Nitzschia spp.	360	9.10E+04		1.71E+06					
Odontella aurita (Lyngbye) Agardh	34194								2.20E+03
Phaeodactylum (?) tricornutum Bohlin	23	5.64E+06	7.24E+06	1.78E+07	1.82E+05	1.82E+05	3.64E+05	1.14E+06	3.41E+06
Pleurosigma salinarum (Grunow) Grunow	14130				1.44E+04	4.00E+02		8.00E+03	2.40E+03
Pseudo-nitzschia delicatissima (Cleve) Heiden	430								6.00E+02
Pseudo-nitzschia seriata (Cleve) Peragallo	596					3.60E+03		8.00E+02	2.16E+04

Bacillariophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Rhizosolenia imbricata Brightwell	11052			2.00E+02	1.44E+04			2.00E+02	
Skeletonema costatum (Greville) Cleve	243	1.10E+06		2.45E+05	2.45E+05	5.77E+04	8.66E+04	1.80E+05	3.01E+05
Skeletonema menzelii Guillard, Carpenter et Reimann	48			4.55E+04	3.64E+05	9.10E+04			
Thalassionema nitzschioides (Grunow) Mereschkowsky	800					5.77E+04			1.40E+03
Thalassiosira proschkinae Makarova	39	1.82E+05	1.14E+06	3.64E+05	2.28E+06	2.28E+06	7.13E+05	2.20E+06	5.69E+05
Thalassiosira tenera Prochkina-Lavrenko	3140								5.92E+05
Bacillariophyceae (total)		1.32E+07	1.62E+07	2.52E+07	5.76E+06	1.00E+07	2.97E+06	1.08E+07	1.84E+07
Chlorophyceae									
Chlamydomonas coccoides Butcher	126								
Chlamydomonas Ehrenberg (sp.)	865		5.69E+05						
Stigeoclonium sp.	2031	4.80E+03							
Chlorophyceae (total)		4.80E+03	5.69E+05						
Chrysophyceae									
Calycomonas ovalis Wulff	28	1.33E+06	5.29E+06	8.93E+05	1.55E+06	2.37E+06	3.72E+05	5.01E+05	9.10E+04
Pseudopedinella pyriformis Carter	113		5.69E+05				2.12E+05		9.10E+04
Chrysophyceae (total)		1.33E+06	5.86E+06	8.93E+05	1.55E+06	2.37E+06	5.84E+05	5.01E+05	1.82E+05
Cryptophyceae									
Hemiselmis virescens Droop	15	1.82E+05		8.02E+05	3.64E+05	2.73E+05	1.37E+05	9.10E+04	1.14E+05

Cryptophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Leucocryptos marina (Braarud) Butcher	69		1.82E+05			2.73E+05			
Plagioselmis (Butcher) Hill (sp.)	33		2.73E+05	1.82E+05	9.10E+04			2.73E+05	1.82E+05
Rhodomonas salina (Wislouch) Hill	184						3.79E+04		
Teleaulax acuta (Butcher) Hill	131			2.84E+05	1.44E+04	5.77E+04	4.33E+04	2.89E+04	
Cryptophyceae (total)		1.82E+05	4.55E+05	1.27E+06	4.70E+05	6.04E+05	2.18E+05	3.93E+05	2.96E+05
Cyanophyceae									
Aphanocapsa Naegeli (sp.)	0.57		2.25E+08	8.87E+06		2.65E+08		5.46E+07	4.55E+07
Dinophyceae									
Ceratium lineatum (Ehrenberg) Cleve	51000								4.00E+02
Dinophysis acuminata Claparede et Lachmann	12505	4.00E+02			1.60E+03				
Gymnodinium gracilentum P.H. Campbell	295				1.82E+05			9.82E+04	
Gymnodinium Stein (spp.)	365	9.10E+04							
Gyrodinium estuariale Hullburt	544					1.82E+05		7.44E+04	
Gyrodinium flagellare Schiller	157						9.10E+04	4.55E+04	
Heterocapsa triquetra (Ehrenberg) Stein	1789	1.44E+04		4.55E+04	1.44E+04				
Prorocentrum micans Ehrenberg	27632			2.00E+02	1.44E+04		7.22E+03		2.00E+02
Prorocentrum triestinum Schiller	732					2.89E+04	7.22E+03	7.22E+03	
Protoperidinium Bergh (spp.)	21993				1.44E+04				

Dinophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Scrippsiella trochoidea (Stein) Loeblich III	6133				9.10E+04	1.44E+04	7.22E+03	2.00E+02	
Dinophyceae (total)		1.06E+05		4.57E+04	3.18E+05	2.25E+05	1.13E+05	2.26E+05	6.00E+02
Prasinophyceae									
Mamiella gilva (Parke et Rayns) Moestrup	65						1.37E+05		
Pachysphaera marshalliae Parke	221		3.79E+05						
Pseudoscourfieldia marina (Throndsen) Manton	12		5.61E+05	4.56E+03		9.12E+03	3.79E+04	7.58E+04	1.14E+04
Pyramimonas parkeae Norris & Pearson	785				2.73E+04	9.12E+03		1.59E+04	
Tetraselmis spp.	540								
Prasinophyceae (total)			9.40E+05	4.56E+03	2.73E+04	1.82E+04	1.74E+05	9.17E+04	1.14E+04
Raphidophyceae									
Heterosigma akashiwo (Hada) Hada ex Hara et Chihara	508								
Autotrophic Ciliates									
Mesodinium rubrum Leegaard	14360	9.10E+04			1.44E+04				
Un-categorized									
Phytoflagellates	65	9.10E+04	4.55E+05	1.42E+05		9.10E+04			9.10E+04
Pico-coccoids (2-3 µm)	28	7.16E+07	1.08E+08	3.78E+07	3.52E+07	8.49E+07	1.50E+07	3.26E+07	1.71E+07

Island Beach State Park Water Column Biovolume 2013									
	Cell Volume μm^3 $cell^{-1}$	**Biovolume μm^3 l^{-1}**							
Bacillariophyceae		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Arcocellulus G.R. Hasle, H.A.von Stosch & E.E.Syvertsen	32					4.37E+07		2.91E+07	
Asterionellopsis glacialis (Castracane) Round	187								
Cerataulina pelagica (Cleve) Hendey	5173	1.59E+10							
Chaetoceros affinis Lauder	1073								
Chaetoceros decipiens Cleve	282								
Chaetoceros simplex Ostenfeld	121					1.10E+07			
Chaetoceros sp.	169	1.15E+08			5.77E+07				
Chaetoceros subtilis Cleve	85	9.67E+07	7.74E+07	1.55E+07					
Chaetoceros subtilis var. abnormis fo. simplex	146	1.66E+07							
Chaetoceros tenuissimus Meunier	85					2.32E+07			
Cocconeis spp.	327		4.72E+06						
Coscinodiscus concinnus Smith	803840						3.22E+08		
Cyclotella atomus Hustedt	40								
Cyclotella choctawhatcheeana Prasad	153	2.61E+08	4.26E+08	6.25E+08	3.74E+08	2.02E+08	2.26E+08	1.38E+09	3.02E+09
Cyclotella striata (Kützing) Grunow	521					4.74E+07			
Cylindrotheca closterium (Ehrenberg) Reimann et Lewin	317		4.57E+06		1.97E+06	1.83E+07	6.86E+06	4.57E+06	2.58E+08

Bacillariophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Dactyliosolen fragilissimus (Bergon) Hasle	1356	4.89E+08							
Diatom Pennate_UNO	450								
Ditylum brightwellii (West) Grunow	15875	9.55E+08							
Entomoneis alata Ehrenberg	11304							8.16E+07	
Guinardia flaccida (Castracane) Peragallo	51286	1.54E+09							
Guinardia striata (Stolterfoth) Hasle	35325								
Leptocylindrus danicus Cleve	490						2.12E+07		
Leptocylindrus minimus Gran	162								
Melosira nummuloides C.Agardh	22899								
Minutocellus scriptus Hasle, von Stosch & Syvertsen	25			1.11E+07		7.07E+05	2.51E+07	2.12E+07	6.13E+07
Navicula spp.	600					2.60E+07	8.66E+06		
Nitzchia longissima (Brebisson) Ralfs	560	8.42E+07	2.42E+07						
Nitzschia spp.	360			7.02E+08			2.05E+07		
Odontella aurita (Lyngbye) Agardh	34194								
Phaeodactylum (?) tricornutum Bohlin	23	3.05E+07	8.50E+07	3.99E+08	2.46E+08	3.14E+07	3.86E+08	6.69E+08	3.52E+08
Pleurosigma salinarum (Grunow) Grunow	14130	1.13E+07		5.65E+06				2.83E+06	
Pseudo-nitzschia delicatissima (Cleve) Heiden	430								1.86E+07
Pseudo-nitzschia seriata (Cleve) Peragallo	596								

Bacillariophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Rhizosolenia imbricata Brightwell	11052	1.33E+07							
Skeletonema costatum (Greville) Cleve	243	2.21E+08							
Skeletonema menzelii Guillard, Carpenter et Reimann	48								
Thalassionema nitzschioides (Grunow) Mereschkowsky	800	1.92E+06					2.89E+07	4.04E+07	
Thalassiosira proschkinae Makarova	39	7.40E+07	1.11E+08		4.44E+06	2.22E+08	2.22E+06		
Thalassiosira tenera Prochkina-Lavrenko	3140					4.53E+07			
Bacillariophyceae (total)		1.98E+10	7.33E+08	1.76E+09	6.84E+08	6.71E+08	1.05E+09	2.23E+09	3.71E+09
Chlorophyceae									
Chlamydomonas coccoides Butcher	126	4.78E+07							
Chlamydomonas Ehrenberg (sp.)	865								
Stigeoclonium sp.	2031		6.45E+08						
Chlorophyceae (total)		4.78E+07	6.45E+08						
Chrysophyceae									
Calycomonas ovalis Wulff	28	2.52E+08	1.82E+08	2.35E+08	7.53E+08	2.03E+08	2.55E+07	1.27E+07	4.78E+07
Pseudopedinella pyriformis Carter	113	4.29E+07							
Chrysophyceae (total)		2.95E+08	1.82E+08	2.35E+08	7.53E+08	2.03E+08	2.55E+07	1.27E+07	4.78E+07
Cryptophyceae									
Hemiselmis virescens Droop	15		3.16E+07	2.44E+07	2.57E+07			2.05E+06	

Cryptophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Leucocryptos marina (Braarud) Butcher	69			6.28E+06	5.89E+07	1.57E+07			
Plagioselmis (Butcher) Hill (sp.)	33	6.26E+06	7.51E+06						
Rhodomonas salina (Wislouch) Hill	184		1.05E+08						
Teleaulax acuta (Butcher) Hill	131	1.49E+07				2.38E+07			
Cryptophyceae (total)		2.12E+07	1.44E+08	3.07E+07	8.46E+07	3.95E+07		2.05E+06	
Cyanophyceae									
Aphanocapsa Naegeli (sp.)	0.57	9.49E+07	1.04E+09	3.53E+08	2.82E+08	2.29E+08	1.85E+08	1.74E+08	1.49E+08
Dinophyceae									
Ceratium lineatum (Ehrenberg) Cleve	51000						1.02E+07		2.04E+07
Dinophysis acuminata Claparede et Lachmann	12505	1.00E+07							
Gymnodinium gracilentum P.H. Campbell	295			1.43E+08	8.39E+07				
Gymnodinium Stein (spp.)	365	1.10E+07	5.27E+06		4.15E+07				
Gyrodinium estuariale Hullburt	544	1.24E+08	2.48E+08		1.86E+08		6.19E+07		
Gyrodinium flagellare Schiller	157	1.79E+07	7.14E+07			2.86E+07		7.14E+06	
Heterocapsa triquetra (Ehrenberg) Stein	1789							1.29E+07	3.39E+08
Prorocentrum micans Ehrenberg	27632								
Prorocentrum triestinum Schiller	732				1.46E+05				1.06E+07
Protoperidinium Bergh (spp.)	21993								

Dinophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Scrippsiella trochoidea (Stein) Loeblich III	6133								
Dinophyceae (total)		1.63E+08	3.24E+08	1.43E+08	3.11E+08	2.86E+07	7.21E+07	2.01E+07	3.70E+08
Prasinophyceae									
Mamiella gilva (Parke et Rayns) Moestrup	65								
Pachysphaera marshalliae Parke	221			2.36E+08	1.01E+08				
Pseudoscourfieldia marina (Throndsen) Manton	12	9.10E+06	1.02E+07	1.09E+06	5.46E+06		6.83E+05		
Pyramimonas parkeae Norris & Pearson	785		4.47E+08	7.14E+07				2.14E+08	6.55E+08
Tetraselmis spp.	540				2.76E+08				1.02E+08
Prasinophyceae (total)		9.10E+06	4.57E+08	3.08E+08	3.82E+08		6.83E+05	2.14E+08	7.57E+08
Raphidophyceae									
Heterosigma akashiwo (Hada) Hada ex Hara et Chihara	508	9.63E+07							
Autotrophic Ciliates									
Mesodinium rubrum Leegaard	14360				1.79E+08				
Un-categorized									
Phytoflagellates	65			4.23E+07		5.92E+06			
Pico-coccoids (2-3 µm)	28	1.93E+09	6.37E+08	2.09E+09	7.43E+09	1.04E+10	8.61E+09	7.31E+09	3.77E+09

Sedge Island Water Column Biovolume 2013									
	Cell Volume μm^3 $cell^{-1}$	**Biovolume μm^3 l^{-1}**							
Bacillariophyceae		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Arcocellulus G.R. Hasle, H.A.von Stosch & E.E.Syvertsen	32			1.37E+07	5.83E+06	5.83E+06	1.21E+06	1.12E+07	7.28E+06
Asterionellopsis glacialis (Castracane) Round	187				2.70E+07			1.87E+08	
Cerataulina pelagica (Cleve) Hendey	5173	6.21E+06	1.49E+08	4.14E+06	2.99E+08		4.15E+07		5.50E+08
Chaetoceros affinis Lauder	1073					6.19E+07			
Chaetoceros decipiens Cleve	282							3.85E+07	
Chaetoceros simplex Ostenfeld	121	1.10E+07		1.56E+06				1.75E+06	
Chaetoceros sp.	169		1.23E+08		2.93E+07		1.01E+05		
Chaetoceros subtilis Cleve	85	7.74E+06				7.74E+06			
Chaetoceros subtilis var. abnormis fo. simplex	146		1.33E+07		1.33E+07				
Chaetoceros tenuissimus Meunier	85	2.04E+05				1.55E+07	3.87E+06	4.64E+07	
Cocconeis spp.	327	4.96E+07			4.72E+06			1.49E+07	
Coscinodiscus concinnus Smith	803840			1.61E+08	6.43E+08				
Cyclotella atomus Hustedt	40	2.15E+08	1.82E+08						
Cyclotella choctawhatcheeana Prasad	153		1.53E+08	5.34E+08	1.81E+08	7.98E+08	9.86E+07	4.92E+08	1.12E+09
Cyclotella striata (Kützing) Grunow	521				3.76E+07	1.20E+08		7.52E+06	4.74E+07
Cylindrotheca closterium (Ehrenberg) Reimann et Lewin	317	4.57E+06	9.15E+06		4.57E+06	6.09E+07	2.29E+06	2.86E+07	4.29E+07

Bacillariophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Dactyliosolen fragilissimus (Bergon) Hasle	1356								1.85E+08
Diatom Pennate_UNO	450	2.05E+08		6.40E+07			1.71E+07		
Ditylum brightwellii (West) Grunow	15875								
Entomoneis alata Ehrenberg	11304								
Guinardia flaccida (Castracane) Peragallo	51286								
Guinardia striata (Stolterfoth) Hasle	35325		2.83E+07						
Leptocylindrus danicus Cleve	490				3.12E+08				
Leptocylindrus minimus Gran	162					3.04E+07	1.23E+07		3.62E+07
Melosira nummuloides C.Agardh	22899			1.18E+09					
Minutocellus scriptus Hasle, von Stosch & Syvertsen	25		3.40E+07	2.34E+07	2.23E+06	2.52E+07	2.29E+07	4.53E+07	1.29E+08
Navicula spp.	600		8.66E+06				8.66E+06		
Nitzchia longissima (Brebisson) Ralfs	560								
Nitzschia spp.	360	3.28E+07		6.14E+08					
Odontella aurita (Lyngbye) Agardh	34194								7.52E+07
Phaeodactylum (?) tricornutum Bohlin	23	1.30E+08	1.66E+08	4.08E+08	4.19E+06	4.19E+06	8.37E+06	2.62E+07	7.85E+07
Pleurosigma salinarum (Grunow) Grunow	14130				2.04E+08	5.65E+06		1.13E+08	3.39E+07
Pseudo-nitzschia delicatissima (Cleve) Heiden	430								2.58E+05
Pseudo-nitzschia seriata (Cleve) Peragallo	596					2.15E+06		4.77E+05	1.29E+07

Bacillariophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Rhizosolenia imbricata Brightwell	11052			2.21E+06	1.60E+08			2.21E+06	
Skeletonema costatum (Greville) Cleve	243	2.67E+08		5.95E+07	5.96E+07	1.40E+07	2.10E+07	4.38E+07	7.32E+07
Skeletonema menzelli Guillard, Carpenter et Reimann	48			2.18E+06	1.75E+07	4.37E+06			
Thalassionema nitzschioides (Grunow) Mereschkowsky	800					4.62E+07			1.12E+06
Thalassiosira proschkinae Makarova	39	7.10E+06	4.44E+07	1.42E+07		8.87E+07	2.78E+07	8.58E+07	2.22E+07
Thalassiosira tenera Prochkina-Lavrenko	3140								1.86E+09
Bacillariophyceae (total)		9.35E+08	9.12E+08	3.08E+09	2.00E+09	1.29E+09	2.66E+08	1.14E+09	4.27E+09
Chlorophyceae									
Chlamydomonas coccoides Butcher	126								
Chlamydomonas Ehrenberg (sp.)	865		4.92E+08						
Stigeoclonium sp.	2031	9.75E+06							
Chlorophyceae (total)		9.75E+06	4.92E+08						
Chrysophyceae									
Calycomonas ovalis Wulff	28	3.74E+07	1.48E+08	2.50E+07	4.33E+07	6.63E+07	1.04E+07	1.40E+07	2.55E+06
Pseudopedinella pyriformis Carter	113		6.43E+07				2.40E+07		1.03E+07
Chrysophyceae (total)		3.74E+07	2.12E+08	2.50E+07	4.33E+07	6.63E+07	3.44E+07	1.40E+07	1.28E+07
Cryptophyceae									
Hemiselmis virescens Droop	15	2.73E+06		1.20E+07	5.46E+06	4.10E+06	2.05E+06	1.37E+06	1.71E+06

Cryptophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Leucocryptos marina (Braarud) Butcher	69		1.26E+07			1.88E+07			
Plagioselmis (Butcher) Hill (sp.)	33		9.01E+06	6.01E+06	3.00E+06			9.01E+06	6.01E+06
Rhodomonas salina (Wislouch) Hill	184						6.98E+06		
Teleaulax acuta (Butcher) Hill	131			3.73E+07	1.89E+06	7.56E+06	5.67E+06	3.78E+06	
Cryptophyceae (total)		2.73E+06	2.16E+07	5.53E+07	1.04E+07	3.05E+07	1.47E+07	1.42E+07	7.71E+06
Cyanophyceae									
Aphanocapsa Naegeli (sp.)	0.57		1.28E+08	5.06E+06		1.51E+08		3.11E+07	2.59E+07
Dinophyceae									
Ceratium lineatum (Ehrenberg) Cleve	51000								2.04E+07
Dinophysis acuminata Claparede et Lachmann	12505	5.00E+06			2.00E+07				
Gymnodinium gracilentum P.H. Campbell	295				5.37E+07			2.90E+07	
Gymnodinium Stein (spp.)	365	3.32E+07							
Gyrodinium estuariale Hullburt	544					9.90E+07		4.05E+07	
Gyrodinium flagellare Schiller	157						1.43E+07	7.14E+06	
Heterocapsa triquetra (Ehrenberg) Stein	1789	2.58E+07		8.14E+07	2.58E+07				
Prorocentrum micans Ehrenberg	27632			5.53E+06	3.99E+08		1.99E+08		5.53E+06
Prorocentrum triestinum Schiller	732					2.11E+07	5.28E+06	5.28E+06	
Protoperidinium Bergh (spp.)	21993				3.17E+08				

Dinophyceae (cont.)		**6/12/2013**	**6/19/2013**	**6/26/2013**	**7/10/2013**	**8/13/2013**	**8/21/2013**	**8/28/2013**	**9/4/2013**
Scrippsiella trochoidea (Stein) Loeblich III	6133				5.58E+08	8.85E+07	4.43E+07	1.23E+06	
Dinophyceae (total)		6.40E+07		8.69E+07	1.37E+09	2.09E+08	2.63E+08	8.31E+07	2.59E+07
Prasinophyceae									
Mamiella gilva (Parke et Rayns) Moestrup	65						8.87E+07		
Pachysphaera marshalliae Parke	221		8.38E+07						
Pseudoscourfieldia marina (Throndsen) Manton	12		6.74E+06	5.46E+05		1.09E+06	4.55E+05	9.10E+05	1.37E+06
Pyramimonas parkeae Norris & Pearson	785				2.14E+08	7.14E+07		1.25E+08	
Tetraselmis spp.	540								
Prasinophyceae (total)		0.00E+00	9.05E+07	5.46E+05	2.14E+08	7.25E+07	8.92E+07	1.26E+08	1.37E+06
Raphidophyceae									
Heterosigma akashiwo (Hada) Hada ex Hara et Chihara	508								
Autotrophic Ciliates									
Mesodinium rubrum Leegaard	14360	1.31E+09			2.07E+08				
Un-categorized									
Phytoflagellates	65	5.92E+06	2.96E+07	9.24E+06		5.92E+06			5.92E+06
Pico-coccoids (2-3 µm)	28	2.01E+09	3.03E+09	1.06E+09	9.86E+08	2.38E+09	4.20E+08	9.13E+08	4.78E+08