Final Report

To

Virginia Coastal Zone Management Program
National Oceanic and Atmospheric Administration

By

The Virginia Institute of Marine Science
College of William and Mary

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FY2011 Task 12 Eelgrass and Bay Scallop Restoration in the Seaside Bays of Virginia.
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Robert Orth[1], Kenneth Moore[1], Mark Luckenbach[1], Stephanie Bonniwell[1], Albert Curry, Jr. [1], Sean Fate[1], Bo Lusk[2], Scott Marion[1], Betty Neikirk[1], David Parrish[1], Erin Shields[1], Barry Truitt[2], and David Wilcox[1]

[1]Virginia Institute of Marine Science, School of Marine Science, 1208 Greate Road, P. O. Box 1346, College of William and Mary, Gloucester Point, Virginia 23062

[2] The Nature Conservancy, Virginia Coast Reserve, 11332 Brownsville Rd., P. O. Box 158, Nassawadox, Virginia 23413

Virginia Coastal Zone MANAGEMENT PROGRAM

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INTRODUCTION

The Virginia coastal bays suffered a catastrophic ecosystem state change in the last century primarily due to a wasting disease that devastated eelgrass beds there followed by a significant hurricane in 1933 that likely eliminated the remaining populations (Orth et al. 2006, unpublished data). This state change from eelgrass to an "unvegetated" bottom dominated by benthic algae resulted in the loss of critical ecosystem services, including the provision of food and nursery habitat for numerous avian and marine species, including the bay scallop, *Argopecten irradians*. The coastal bays supported a significant commercial scallop fishery prior to these events, that never recovered following the eelgrass decline (Orth et al. 2006). While eelgrass eventually rebounded from the pandemic decline both in the Chesapeake Bay and in many coastal bays along the eastern seaboard of the United States (Cottam and Munro 1954), there are no records of eelgrass recovery in the VCR coastal bays until the mid-1990s (Orth et al. 2006).

In 1997, the discovery of two small patches of eelgrass in South Bay, one of the Virginia coastal bays, suggested that this bay could support the growth of eelgrass and that the limiting issue for expansion of eelgrass may be the lack of seed input. Based on this we subsequently began an attempt to restore eelgrass to the coastal lagoons with seeds. In 1999, we initiated large scale (>100 m^2 areas) seed introductions using millions of seeds starting in South Bay and in later years expanding to three additional bays where the relative isolation from the nearest seed-producing beds may have historically resulted in rare, low-density seedling recruitment. The success of this restoration effort has been documented in many final reports and published papers (see papers in Orth and McGlathery 2012) and represents one of the most successful eelgrass restoration efforts in the world today. This success led to the initiation of the program to re-introduce the bay scallop back to these coastal bays with initial attempts showing moderate successes documented in field surveys conducted in 2011 and 2012.

The goal of this project was to continue the enhancement of eelgrass and bay scallop to these coastal bays. Specific objectives of the FY 2011 funds were: 1. Plant eelgrass using seeds to increase the recovery of the eelgrass beds into the Virginia coastal bays region; 2. Determine seedling establishment rates and evaluate the effectiveness of the seed planting; 3. Monitor water quality conditions to assess changes that may be associated with the eelgrass recovery and to identify new potential areas for restoration activities; 4. Assess eelgrass bed growth and expansion; and 5. Continue bay scallop restoration efforts initiated in 2009 with NOAA's American Reinvestment and Recovery Act Funds and supported by FY2009 Coastal Zone support, Task 10.

STUDY SITES

Eelgrass and bay scallop restoration studies were conducted in the four adjacent sub-basins along the lower Delmarva Peninsula in 2012: South Bay, Cobb Bay, Spider Crab Bay and Hog Island Bay (Figure 1). The coastal bays are part of the Virginia Coast Reserve Long-Term Ecological Research site. We initiated large scale eelgrass restoration with seeds in South Bay in 1999, Cobb Bay in 2001, Spider Crab Bay in 2003, and Hog Island Bay in 2006 following at least 1-yr survival of test plots in each bay. Spider Crab Bay was identified as the bay to receive seeds in 2012. Water quality was measured in all four bays using DATAFLOW while continuous sensors were located in both South and Spider Crab bays. Bay scallop restoration efforts were concentrated in South Bay.

METHODS

Seed collection and distribution

Eelgrass flowering shoots with maturing seeds were harvested either by hand or by mechanical harvester in May/June, 2012, and stored in aerated, flow-through tanks until seed release following procedures described by Marion & Orth (2010) either at the Gloucester Pt. or Oyster seed curing facilities. Seeds were separated from the senescing shoots and held in recirculating seawater tanks until distribution in September or October, just prior to the normal period of seed germination in this region (Moore et al. 1993). The proportion of viable seeds was determined just before distribution by individually assessing firmness and fall velocity of seeds in subsamples as detailed in Marion and Orth (2010). Batches of seeds with targeted numbers of viable seeds for individual restoration plots were measured volumetrically, and all seed numbers reported here refer to viable seeds.

In the fall, 2012, eelgrass seeds were hand broadcast from a boat into pre-determined un-vegetated plots in Spider Crab Bay. In addition, several small plots (< 0.5 acres) were established from seeds injected into the sediment from a modified seed planter developed earlier (Marion and Orth 2010). Fall broadcasting has been shown to maximize establishment rates (Marion & Orth 2010). While plot sizes have varied in previous years work (2001-2011) from 0.01 to 2 hectares at the different bays, plot size during the 2012 project was 0.4 ha (one acre) for most of the plots (Table 1). Seed densities ranged from 106K to 260K seeds per plot. Two test plots (50 m x 2 m) with seeds (approx. 10K seeds each) were established in Black Duck Cove where test plots had been established the previous year. We also broadcast seeds into a one acre plot in Black Duck Cove adjacent to the 2011 test plots at a seed density of 142K seeds per acre.

Germination rates of seeds collected in 2012 were estimated by planting replicate batches of either 10 or 20 seeds at approximately 5-7 mm depth in sandy sediments (generally greater than 95% sand and < 1% organic matter) (Moore et al. 1993) in chilled, re-circulating seawater inside a greenhouse. Water temperatures were adjusted to follow ambient water temperatures in the field. Germination was considered successful with the emergence of the cotyledon and first leaf.

Field assessment of seedling establishment was made in April, 2013, six months after broadcast. Since seeds become rapidly incorporated into the sediment and do not move far from where they settle to the bottom (Orth et al. 1994), we were able to accurately assess establishment rates in seeded plots. Seeds typically germinate in early to late November in this region (Moore et al. 1993) and grow slowly during the winter months when water temperatures range from 0° to 5° C. Divers counted the number of seedlings in 0.5 m belt transects along the two diagonals of designated plots and adjusted to total number of seedlings per 0.4 ha. This number was then divided by the number of seeds broadcast into the plot.

Eelgrass Assessment - Broad Scale

Eelgrass bed areas were delineated from aerial photography acquired in 2012 (we had been acquiring aerial photography annually from 2001 through 2011, except for 2005). Black and white photography was acquired at a scale of 1:24,000 from an altitude of 3,658 m with a mapping camera, following acquisition timing guidelines that optimize visibility of eelgrass beds (Orth et al. 2010). Acquisition timing rules specified tidal stage (+/- 90 minutes of low tide), plant growth season (peak biomass), sun angle (between 20-40^{o}), atmospheric transparency (cloud cover less than 10%), water turbidity (edge of grassbeds should be visible), and wind (less than 10 kts) (Dobson et al. 1995). Images incorporated 60% flight-line overlap and 20% side lap. Two flight lines were flown each year covering all shorelines and adjacent shoal areas of the four bays where the seed addition work was conducted. Aerial photography was scanned from negatives at a 1 m resolution and orthorectified using ERDAS LPS image-processing software (ERDAS, Atlanta GA). Eelgrass bed boundaries were then directly photo-interpreted on-screen while maintaining a fixed scale using ESRI ArcMap GIS software (ESRI, Redlands CA) (Orth et al. 2010). Eelgrass beds were categorized as very sparse (1-10% cover), sparse (11-40% cover), moderate (41-70% cover), or dense (70-100% cover) based on a visual estimate of the percent cover on the photograph (Orth et al. 2010). For broad-scale distribution assessments in this paper, we collapsed the four categories into two: very sparse to sparse (1-40%) and moderate to dense (41-100%). Ground surveys were conducted in the bays each year to confirm the occurrence of eelgrass identified in the photography within and outside the boundaries of the seeded plots.

Water Quality

Two complementary approaches to documenting water quality conditions were continued in 2012 (Figure 1). Broad spatial patterns in water quality were documented using continuous underway sampling (DATAFLOW) in 2012 as in previous years (this effort commenced in 2003 and has been conducted annually, Orth et al. 2012). In addition, temporal patterns in water quality were documented through sensor deployments at two fixed stations, South Bay and Spider Crab Bay. The DATAFLOW cruise track traversed restoration areas in all four bays: South Bay, Cobb Bay, Spider Crab Bay, and Hog Island Bay. Cruise tracks were expanded from the initial track in 2003 over South Bay as successive bays were added to the restoration effort. By 2005 the cruise track covered all four major bays and remained similar through 2012. Cruises were generally conducted monthly throughout the eelgrass growing season, from March through November, with nine cruises conducted in 2012. While the length of cruise tracks in vegetated and unvegetated areas varied annually as the eelgrass beds developed and expanded, the track in 2012 has encompassed all four bays as it did in 2011.

The DATAFLOW underway sampler recorded 'in vivo' measurements of surface water quality taken at 2-3 second intervals (0.25 m depth below surface; approximately every 50 m) along each cruise track. Measurements included turbidity, chlorophyll fluorescence, temperature, salinity, pH, dissolved oxygen, GPS location and depth using a YSI 6600 EDS sensor array (YSI Inc., Yellow Springs, Ohio that has been synchronized with various models of Garmin GPSMAP Sounders including the 168, the 498 and the 540S (Garmin Ltd., Olathe, KS)). All sensors on the YSI 6600 EDS were both pre-cruise calibrated and post-cruise checked according to YSI standard procedures. In addition to the continuous underway sensor measurements, 5 calibration and verification stations were sampled at discrete locations spaced along each cruise track for total suspended solids, extracted pigment chlorophyll, and light attenuation profiles. Total suspended solids (TSS) were determined by filtration of known volume of seawater (pre combusted Gelman, Type A/E), rinsing with freshwater, and drying at 60ºC. Chlorophyll a was collected on Whatman GF/F glass fiber filters, extracted in a solvent mixture of acetone, dimethyl sulfoxide, and 1% diethylamine (45:45:10 by volume) and determined fluorometrically (Shoaf and Lium 1976). Chlorophyll concentrations were uncorrected for phaeopigments. Chlorophyll fluorescence measurements were converted to extracted chlorophyll equivalents reported in this paper by developing a regression between extracted and fluoresced chlorophyll using the extracted chlorophyll and fluoresced samples taken simultaneously at each verification station for the entire study period. Diffuse downwelling attenuation of photosynthetically available radiation (PAR) was determined by triplicate water column measurements of downwelling photosynthetic photon flux density measured with a LI-COR, LIO-192, underwater cosine corrected sensor (LI-COR Biosciences, Lincoln, Nebraska). Measurements were taken every 25 cm from 10 cm below the surface to a depth of 1.0 m. Similar to the YSI chlorophyll measurements, YSI turbidity measurements were converted to light attenuation equivalents using regression analysis relating turbidity to downwelling light attenuation coefficients (Kd) using all simultaneously measured light profiles and turbidities taken at the verification stations over the course of the study.

In order to capture high frequency temporally intensive water quality information, a YSI 6600 EDS identical to that used in the DATAFLOW was deployed at a fixed monitoring station beginning in South Bay in 2003, and a second station added in July, 2011, in Spider Crab Bay both currently with EcoNet real time telemetry capability. Both stations have been monitoring year round since 2011. In May 2010 the South Bay station was also equipped with an EcoNet telemetry unit (YSI Inc., Yellow Springs, Ohio) which allowed the transmission of real-time data. In July 2011 the Spider Crab Bay station was similarly equipped. Real-time data are available through the VECOS web site (www.VECOS.ORG).

Scallop Seed Production

During the period covered by this award F2 and F3 generations of bay scallops were maintained within a field nursery system and used as brood stock for hatchery spawns to produce offspring for deploying in the eelgrass beds in South Bay and Cobb Bay. All of these scallops originated from parental stock of *Argopecten irradians concentricus* collected from Bogue Sound and Core Sound, North Carolina during 2009 and 2010.

Gametogenesis was initiated in adult scallops held in the field and allowed to feed on natural phytoplankton assemblages. Several weeks prior to spawning, broodstocks were brought into the Castagna Shellfish Research Hatchery at the VIMS Eastern Shore Laboratory and fed a diet of mixed species of culture phytoplankton. Ripe animals are thermally induced to spawn and larvae reared using standard culture techniques and fed on a diet of mixed species of cultured phytoplankton.

Following the larval period, hatchery-produced scallops were placed in a land-based, flow-through nursery system, where they were generally reared for 4 – 6 weeks until they exceed 2 mm in shell height. Once the scallops were large enough to be retained within a 2 mm mesh, they were transferred to mesh bags and placed in surface floating cages at a field-based nursery located near Wachapreague Inlet, VA.

Once scallops attain a shell height between 10 – 20 mm they were transferred from the floating cages in the field-based nursery to larger mesh bags inside bottom cages within grass beds in South Bay and Cobb Bay.

Maintenance of Scallop Spawning Stocks in Grass beds

Our scallop restoration strategy is predicated on maintaining spawning stocks from hatchery-produced cohorts in cages within the target eelgrass beds. The choice to use caged broodstock is based upon the need to maximize survival, especially during the summer months when predation rates are high, and fertilization efficiency, by maintaining spawning animals in close proximity to one another. The cages are constructed of plastic-coated wire screening with 1-inch square mesh opening. Two hundred bay scallops are placed into plastic mesh bags (1/4 to 1/2-inch mesh opening) and two bags are placed in each cage. The cages and bags require periodic scrubbing with a wire brush to remove fouling organisms that restrict water flow. At the beginning of the project period all of the scallops deployed in this manner were in the South Bay grass bed, where all of our scallop restoration efforts to that point had occurred.

Adult scallops produced from spawns during fall 2011 and spring, 2012, were maintained in cages within grass beds in South Bay and Cobb Bay throughout this period. The cages were inspected shortly after Hurricane Sandy and no major damage or loss was observed. The majority of these scallops were maintained in cages in the grass beds until spawning occurred in spring 2013, after which time they were removed from the cages and free planted in the grass beds. Approximately 350 scallops from the spring 2012 cohort and 100 scallops from the 2011 cohort were removed from the grass bed on 3/11/2013 and returned to the laboratory to serve as spawning stock for spawns during spring 2013. An assessment of these stocks on 3/19/2013 showed no evidence of sperm or egg production at that time. These animals were then used to produce spawns conducted in our subsequent project year and will be reported on in FY12 Task 11 reports.

Assessment of Wild Populations

The ultimate goal of our scallop restoration project is to establish a self-sustaining, wild meta-population distributed among numerous restored eelgrass beds in the coastal bays. Thus, assessing the abundance of wild scallops in the grass beds is of critical importance.

In our previous final report (FY 2009, Task 10), we reported estimates of wild scallop abundance in the South Bay grass bed based upon independent diver surveys and suction samples collected as part of surveys conducted for other purposes. We noted in that report that each of these surveys had significant limitations - the diver surveys likely missed most small scallops and the suction samples were of inadequate size and number to expect to collect many scallops. Thus, we developed a new survey design that employed both suction sampling and diver surveys, with the former targeting small scallops (<20 mm and typically < 1year-old) that are attached to eelgrass blades and the latter targeting larger, older scallop that reside on the bottom substrate.

The suction samples were collected by deploying a 1.27 m^2 weighted ring with attached mesh extending through the water column at randomly determined locations throughout the grass bed and using a gasoline powered suction sampler with attached 2 mm mesh bag to extract the contents within the ring by methodically moving the suction head around the inside of the ring for a 5 min. period. The contents of the mesh bag from each sample were immediately processed on the boat by counting and measuring each bay scallop collected. A preliminary study, using hatchery produced scallops added to the ring enclosures, yielded a recovery efficiency of 52% for small (< 20 mm) scallops. We applied this correction to the numbers of scallops collected in our samples based upon these measured efficiencies.

The total area of the South Bay grass bed, upon 2011 aerial imagery was estimated to be 382 hectares. Using a GIS-based grid overlain on this imagery, a total of 120 randomly located stations for suction sampling were identified. GPS coordinates were used to locate stations in the field. Samples were then collected, as described above, by visiting as many of these sites as possible over a 3-day period (7/17/12 – 7/19/12) during a period that range from approximately the midpoint between high and low tides to the midpoint between low and high tides.

Diver surveys to census larger scallops were conducted by randomly selecting point locations within the grass bed. These locations served as starting points for five haphazardly directed transects. Five separate divers then swam along the transect randomly placing 1 m^2 quadrats and thoroughly search the area within the quadrat, largely by touch as visibility was often poor. Each diver targeted collecting ten quadrats per transect, though the actual number sometimes varied depending upon time available on station and tidal stage. As with the suction samples, the number of scallops collected m^{-2} was multiplied times the 3.82×10^6 m^2.

RESULTS

Eelgrass Seeding
In 2012, 7.3 million seeds were broadcast into 14.2 ha (35 acres) in Spider Crab Bay (Table 1). To date 50.8 million seeds have been broadcast into 152.7 ha (377 acres) (Table 1, Figure 2).

Eelgrass Seedling Establishment
Seeding was successful each year but seedling establishment rates varied among individual plots, bays, and years. The mean seedling establishment rate for all evaluated plots seeded in 2012 was 3.1% (range of 0.1 – 6.8%), compared with median rates of 7.0, 2.0, 6.3 and 6.4% recorded at South, Cobb, Spider Crab, and Hog Island bays, respectively, for all years combined (2001-2012). Laboratory germination rates of seeds previously assessed as viable were greater than 80%, confirming that the seeds we dispersed were largely viable seeds.

Meadow Expansion and Development
In 2012 we mapped 1,878.5 hectares (4639.8 acres) of bottom containing eelgrass, an increase of 109.4 ha (270.1 acres) from 2011 (Figure 3).

South Bay, where seeding began in 1999, showed the greatest spread and increase in coverage of the four bays. Eelgrass was first mapped for this bay in 2001, when 15.7 ha was recorded, all being sparse eelgrass cover (Figure 3). This increased to 200 ha, also sparse cover, in 2006. By 2012, 1,067.2 ha (2,656.6 acres) were mapped, with 86.3% classified as moderate to dense cover (Figs. 4, 5).

Seed distribution in Cobb Bay began in 2001. Eelgrass was first mapped for this bay in 2003 when 3.9 ha, all sparse cover, was recorded (Figure 3). By 2006, 41 ha were mapped with 11% considered moderate to dense cover. By 2012 eelgrass coverage increased to 359.72 ha (888.5 acres), with 93.0% classified as moderate to dense cover (Fig. 4).

Seed distribution in Spider Crab Bay began in 2003. Eelgrass was first mapped in this bay in 2004 when only 0.3 ha, all sparse cover, was recorded (Figure 3). In 2006, 1.6 ha were mapped as all sparse cover. By 2012, 268.7 ha (663.8 acres) were mapped, with 30.7% considered moderate to dense cover (fig. 4).

Seed distribution in Hog Island Bay began in 2006. Eelgrass was first mapped in this bay in 2007 when 25.5 ha, all sparse cover, were recorded (Figure 3). By 2012, 182.8 ha (451.5 acres) were mapped, with 64.8% considered moderate to dense cover Fig. 6).

In Black Duck Cove, very few plants were noted in the spring 2012 and 2013 assessments.

Water Quality

DATAFLOW provided a characterization of each bay's conditions over short spatial scales as evidenced from one cruise in July, 2012 (Figure 7). Here the main restoration areas within South, Spider Crab, Cobb Island and Hog Island Bays are identified along the cruise track. Salinity demonstrated consistent spatial levels among the various bay restoration sites with concentrations typically between 29.5 and 31.0 PSU. Temperature, especially during the summer months as presented here, showed some variability with lower summertime temperatures in the vicinity of the inlets. This is consistent with that observed in 2011. Dissolved oxygen and pH concentrations were generally lower near the western shore compared to several of the restoration sites, although some anomalies were noted during this particular cruise. Turbidity levels varied over short distances as much as 10-15 NTU with levels during this typical cruise ranging between 5 and 20 NTU with the main restoration sites. Chlorophyll levels varied in range among the four restoration sites usually within 5-15 $\mu g l^{-1}$ during any particular cruise. These concentrations were also consistent with 2011 conditions.

Long-term integrated monthly water quality conditions measured using DATAFLOW across both vegetated and unvegetated areas of the bays for all restoration years combined (2003-2012) showed that during the March-November eelgrass growing season water temperatures ranged from less than 5 °C to greater than 25 °C (data not shown) with medians between 20 and 22 °C (Table 2). Salinities ranged between 28 and 34 PSU (data not shown) with median levels between 31 and 32 PSU with very similar seasonal levels among the sites. Dissolved oxygen was always high with median levels between 7.4 and 7.8 mg l^{-1} while pH was well buffered at 7.9 units. Turbidity levels were generally low with median seasonal levels between 8 and 9 NTU. Comparison of turbidity with light attenuation measurements in this study indicated that turbidity levels of approximately 10 NTU equate to a light attenuation coefficient (Kd) of approximately -1.5, or approximately 22 percent of surface light through the water (PLW) reaching the bottom at a depth of 1m. Integrated median growing season water quality conditions for all cruises within each study year and bay from 2003 to 2012 showed that 2005 had the highest turbidities across all bays monitored; however turbidities in 2012 were the highest since that earlier year (Table 3).

Figure 8 presents the median, 25% and 75% quadrille, maximum and minimum of the turbidity levels recorded by DATAFLOW across the four restoration areas during the cruises for these same periods during the overall 2003-2012 restoration study period. The slightly higher turbidity levels observed at all sites in 2012 compared all years since 2005 are demonstrated here. Approximately 50% of the DATAFLOW observations were between 10 and 20 NTUs at all the sites during 2012. Chlorophyll concentrations had median seasonal levels of 5- 6 µg $^{l-1}$. The long term monitoring results shows that from 2003-2012 overall differences among the bays were low. Integrated seasonal chlorophyll levels were also highest in 2005 (Table 4) although again concentrations in 2012 were higher than 2011. Figure 9 shows the median, quartiles and ranges of the chlorophyll measurements for each of the years. While the overall range in chlorophyll concentrations did not appear to increase in 2012, suggesting there were no significant bloom events, the slightly higher median concentrations were evident.

Daily mean salinities measured at the South Bay and Spider Crab Bay restoration site monitoring station varied between 29 and 33 PSU with a gradual seasonal increase observed from March to November 2012 at both sites (Figure 10). Summertime salinities were similar between the sites although the range in South Bay was slightly greater than Spider Crab Bay (Figure 11). Slightly higher levels recorded for the same period in 2012 compared to 2011.

Daily mean water temperatures showed seasonal increases with maximums of approximately 30 °C observed in July and minimums of 5 °C in January (Figure 12). Overall, median water temperatures in 2012 were approximately 1 °C higher in 2012 than 2011 (Figure 13).

Dissolved oxygen concentrations followed similar seasonal trends with lowest values observed during the warmest summertime periods (Figure 14). Mean levels never fell below 5 mg^{-1} indicating that these area remain well oxygenated throughout the year. Summertime concentrations were generally between 6-7 mg^{-1} with lowest concentrations rarely falling below 4 mg^{-1} (Figure 15). Median concentrations were lower in 2012 compared to 2011.

pH levels were well buffered and ranged between 7.8 and 8.3 with levels (Figure 16) generally highest in the winter. Median summertime levels were nearly identical between the restoration sites and between 2011 and 2012 (Figure 17).

Turbidity levels gradually increased in both restoration sites with highest levels in July (Figure 18). Increases in Spider Crab Bay were higher than those observed in South Bay. Both sites demonstrated similar short-term turbidity increases, especially during November 2012. These short term increases were likely related to storm and other wind events. Summertime turbidity levels in South Bay were considerably higher in 2012 compared to 2011, as also observed in the DATAFLOW cruise measurements for 2012. Concentrations in South Bay were overall much lower in South Bay compared to Spider Crab Bay, especially during the summer (Figure 19). Previous studies here described in the FY2009 Final Report shows that this is likely related to the greater abundance of restored eelgrass vegetation present at the South Bay restoration site. The vegetation reduces re-suspension and greatly reduces turbidity. As the eelgrass vegetation continues to become re-established these differences should decrease.

Chlorophyll concentrations remained generally low (< $10 \mu g^{-1}$) with highest levels typically observed in July (Figure 20). Episodically high levels were most likely related to re-suspension of phyto-benthos. Concentrations in the summer were similar between 2011 and 2012 although 2012 showed higher median concentrations (Figure 21). As with turbidity measurements, concentrations of chlorophyll were higher in Spider Crab Bay than South Bay. Again, both the baffling effects of the more abundant eelgrass at South Bay as well water column filter feeders present in the vegetation can result in lower phytoplankton abundances in areas with higher eelgrass abundance.

Scallop Seed Production

Six separate spawns were conducted during a portion of the period covered by this award, resulting in the production of 6.52 million competent to settle larvae being placed in the land paced nursery system. As result of overlapping award periods, these results are reported in greater detail our FY2009 Task 10 Annual Report (see Table 5) and will not be further detailed here.

Maintenance of Scallop Spawning Stocks in Grass beds

At the beginning of the period covered by this award, we maintained approximately 25,000 and 30,000 adult scallops from fall 2010 and spring 2011 spawns, respectively, in cages in South and Cobb bays. As reported in our FY2009 Task 10 report, we released the 2010-spawned scallops directly into the grass beds during the spring of 2012, but we continued to maintain the stocks produced from 2011 spawns. An additional 4,150 scallops produced during spring spawns in 2012 were deployed in cages in South Bay and maintained through the duration of this project year.

Assessment of Wild Population

A total of 85 1.27 m^2 suction samples were collected over the 3-day sampling period in July, yielded a total of 29 small scallops. Appling the capture efficiency estimate and scaling to the size of the entire grass bed yields an estimate of 1.97 million scallops in the 0 – 1 year class. A total of 1748 1-m^2 quadrats sampled by divers yielded an estimate 26,224 large scallops (1 – 2 year class). These two approaches resulted in an estimated wild population of approximately 2 million scallops in the grass bed. These wild scallops are assumed to be the offspring of caged scallops deployed in the grass bed in 2010 to 2012 and, though the wild population remains too small to be self-sustaining, these findings provide a validation of our restoration strategy and an indication of early success in this restoration effort.

DISCUSSION

Eelgrass Bed Development

The use of seeds in the recovery of eelgrass in the Virginia coastal bays continued successfully in 2012. The collection process of harvesting flowering shoots for seeds, followed by maintenance of the shoots in our seed curing tanks until seeds are released, removal of seeds from these tanks once seeds are fully released, and storage of seeds in our greenhouse under appropriate environmental conditions of temperature and salinity, yielded a large number of seeds that we were able to use in the restoration process. Over 7 million seeds were distributed into 35 one acre plots in Spider Crab Bay in 2012. Spider Crab Bay was targeted for continued restoration given that the spread of eelgrass in South and Cobb bays has resulted in the cover of most available bottom in these two bays. We anticipate some continued spread into some marginal areas in South and Cobb bays but the increase will certainly not be what we observed in previous years as noted in Figure 3. It is interesting to note that while there has been no significant spread of eelgrass in South and Cobb bays in the last year, the existing beds have gotten denser with 86 and 93% of the total area in South and Cobb bays, respectively, now mapped as dense, indicating infilling of many sparse areas by seeds produced in the existing eelgrass.

Eelgrass in Spider Crab Bay has been increasing over the last few years noted in Figure 3, albeit more slowly that South and Cobb bays, and despite significantly more seeds being dispersed here. Water quality conditions in Spider Crab Bay are apparently somewhat less favorable than what we are noting in South and Cobb bays. In addition, eelgrass here has been influenced by the 2 hot summers we had in 2005 and 2010 which led to high mortality of seedlings from the 2004 and 2009 broadcasts. We noted that adult plants survived those hot summers but seedlings did not suggesting a greater susceptibility of seedlings to stressful conditions than adult plants. We do hypothesize that eelgrass will continue to spread here and reach cover categories observed in South and Cobb bays (Figure 3) unless environmental conditions such as high temperatures would continue to negatively affect seedlings. Total bottom area in Spider Crab Bay is large and the exact end point in total cover may be as high as South Bay. Spider Crab Bay has a large area with water depths greater than 1.5 m at mean low water which initially may not support eelgrass based on our understanding of the current depth limits in these coastal bays (McGlathery et al. 2012). However, it is possible that as eelgrass expands and fully covers the bottom area in these shallower sections of Spider Crab Bay it may modify conditions (Orth et al. 2012) in areas adjacent to this grass and allow eelgrass to grow at deeper depths.

There was a small decrease in areal coverage of eelgrass in Hog Island Bay in 2012 from 2011. Field observations in 2012 by UVA staff (McGlathery, personal communication) also noted a decrease in eelgrass shoot density in their annual assessment of the Hog Island Bay bed. Continued monitoring of this bay will hopefully reveal whether this loss is due to water quality changes or other unknown factors.

We have not observed significant survival of test plots in Black Duck Cove. Sediments here are very muddy and during our field assessments, we have noted very poor water clarity suggesting this cove may not support eelgrass.

Water Quality in the Virginia Coastal Bays

Water quality monitoring in 2012 indicates that overall, water quality remains high for eelgrass growth and restoration in all of the coastal lagoon areas measured here. Both turbidity and phytoplankton concentration in 2012 were higher than those observed in 2011, but were well within the current tolerance of the eelgrass. Overall, South Bay continues to show slightly better water quality than Spider Crab Bay, and this can be attributed to the greater restored eelgrass abundances there. The capacity of these eelgrass beds to improve water quality conditions for their growth is well evident in these coastal bay restoration sites. However, as demonstrated in 2012, increases in turbidity (and consequently reduced light for growth) and temperature can occur from year-to-year. Therefore it is important that restoration activities, followed by natural expansion, be continued in areas with low and recovering eelgrass abundances, so that these effects of climate or other natural, as well as anthropogenic perturbations can be minimized through the positive feedbacks that healthy and well established beds can provide for themselves.

Scallop Restoration

To date our efforts to restore bay scallops to the coastal bays have yielded very promising results. Our earlier work (funded by the Keith Campbell Foundation for the Environment, NOAA ARRA and CZM FY 2009 Task 10) established several important facts that are guiding our restoration efforts:

- Direct transfer of adult spawning stock from NC to VA is not a viable restoration option, because bay scallops in NC and transported to VA were observed to have numerous attached invertebrates that are not native to Virginia;

- Field-ripened scallops collected from NC and held in a quarantine hatchery can be successfully spawned during the spring and early fall;

- Larvae from these spawns can be successfully reared through the larval, juvenile and adult stages to VA develop brood stocks for use in restoration efforts;

- Free-planting of small scallops into eelgrass beds early in the summer results in high mortality rates, while free-planted juveniles in the fall are subject to lower mortality rates; and,

- Good survival is achieved through spawning of scallops planted in cages within the eelgrass beds.

These findings have led us to develop a restoration strategy with the following key elements:

- Development and maintenance of a Virginia spawning stock originally derived from NC stocks of *C. irradians concentricus* with occasional outcrossing with new animals from NC to avoid inbreeding depression;

- Rear hatchery-spawned scallops in the spring through the hatchery and nursery phases until they are large enough to deploy in cages in the eelgrass beds in late summer, where they will spawn in the fall and in the following spring; and,

- Rear hatchery-spawned scallops in the fall only to small juvenile stage and during late fall free plant in the eelgrass bed where they will spawn the following spring and fall.

Our research during the phase of the project covered in this report has provided a strong proof of concept for this restoration strategy. With a little over 100,000 bay scallops deployed as spawning stocks to date in cages within the grass bed and a population estimate of nearly 2,000,000 in the South Bay grass bed, we are encouraged that our restoration strategy is viable. Nevertheless, we are convinced that it will be necessary to increase the numbers of scallops reared and planted into the grass beds, both to increase densities within a single grass bed and to expand scallop plantings into multiple grass beds, to establish a region meta-population that will help to ensure that we restore viable and resilient bay scallop population to the region.

Acknowledgments
We appreciate the numerous staff and students, who made the success of this project possible, notably Jim Goins, Steve Snyder, Corey Holbert, Paige Ross, Stephanie Benwitz, Sarah Sumoski, Jamie Blackburn, as well as the numerous citizens who volunteered to help collect eelgrass seeds, and summer interns at VIMS Wachapreague who helped in the bay scallop assessment. Additional funding for this project was provided by the grants from the Virginia Recreational Fishing License Fund, the American Recovery and Reinvestment Act with funding to NOAA, The Nature Conservancy, as well as private grants from the Allied-Signal Foundation, Norfolk-Southern, and the Keith Campbell Foundation for the Environment.

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FIGURES

Figure 1. Study region in the lower Virginia coastal bays. Hatched polygons represent eelgrass seed distribution regions. The solid line across all four bays represents the boat track for continuous underway water quality sampling (DATAFLOW) cruises. The open circles in South Bay and Spider Crab are the sites of the continuous monitoring stations.

Figure 2. Cumulative area of seeding and total area estimate from the aerial mapping for all four seaside bays through 2012.

Figure 3. Area of seeding in each of four bays (left axis), and area mapped in two density classes by aerial photography each year (right axis). ND indicates no mapping data for 2005.

Figure 4. USGS 1:24,000 Cobb Island, VA, quadrangle showing in South, Cobb, and Spider Crab bays with areas that were mapped with SAV(See VIMS SAV 2012 Annual SAV Monitoring Report for a full description the site and area computation for each of the mapped beds identified in this figure: http://vims.edu/bio/sav/sav12/index.html).

Figure 5. USGS 1:24,000 Ship Shoal Inlet, VA, quadrangle showing in South, Bay with areas that were mapped with SAV(See VIMS SAV 2012 Annual SAV Monitoring Report for a full description the site and area computation for each of the mapped beds identified in this figure: http://vims.edu/bio/sav/sav12/index.html).

Figure 6. USGS 1:24,000 Quinby Inlet, VA, quadrangle showing in Hog Island Bay with areas that were mapped with SAV(See VIMS SAV 2012 Annual SAV Monitoring Report for a full description the site and area computation for each of the mapped beds identified in this figure: http://vims.edu/bio/sav/sav12/index.html).

Figure 7. Water quality parameters measured along the DATAFLOW track beginning and ending at Oyster, Virginia, as recorded on July, 2012. Boxes around data indicate the locations along the track of target restoration areas shown in Figure 1. SO - South Bay, CO - Cobb Island, SC - Spider Crab Bay, HO – Hogg Island Bay, SS Inlet – Sand Shoal Inlet, GM Inlet – Great Machipongo Inlet, • South Bay and Spider Crab Bay continuous monitoring stations.

Figure 8. Box plots showing DATAFLOW turbidity concentrations (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data) from four restoration bay areas for the March-November periods from 2003-2012.

Figure 9. Box plots showing DATAFLOW chlorophyll concentrations (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data) from four restoration bay areas for the March –November periods from 2003-2012.

Figure 10. Daily mean salinity concentrations at South (SB) and Spider Crab (SC) Bays. January –December 2012.

Figure 11. Salinity comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 and 2012. (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure12. Daily mean water temperatures at South (SB) and Spider Crab (SC) Bays. January – December 2012.

Figure 13. Water temperature comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 and 2012 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 14. Daily mean dissolved oxygen concentrations at South (SB) and Spider Crab (SC) Bays. January –December 2012.

Figure 15. Dissolved oxygen comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 and 2012 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 16. Daily mean pH concentrations at South (SB) and Spider Crab (SC) Bays. January – December 2012.

Figure 17. pH comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 and 2012 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

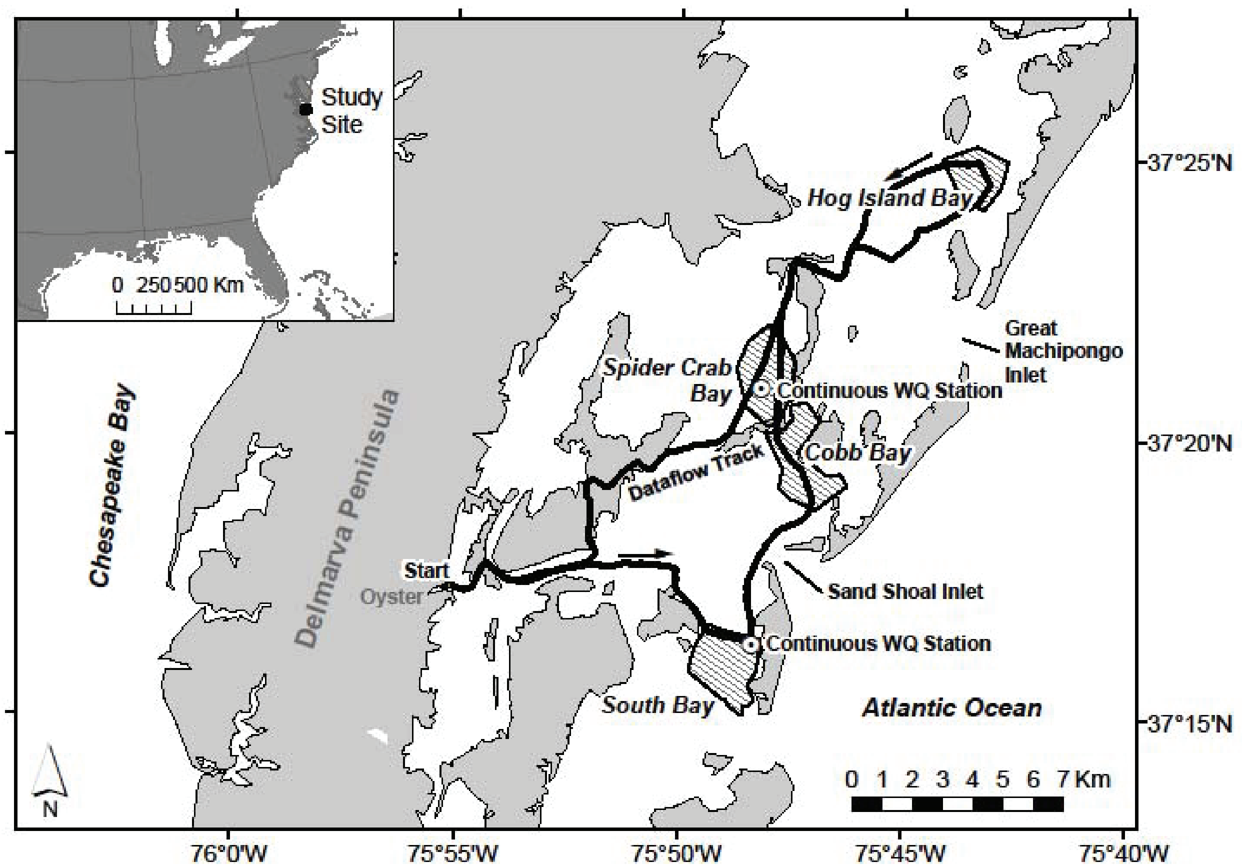
Figure 18. Daily mean turbidities at South (SB) and Spider Crab (SC) Bays. January –December 2012.

Figure 19. Turbidity comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 and 2012 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 20. Daily mean chlorophyll concentrations at South (SB) and Spider Crab (SC) Bays. January –December 2012.

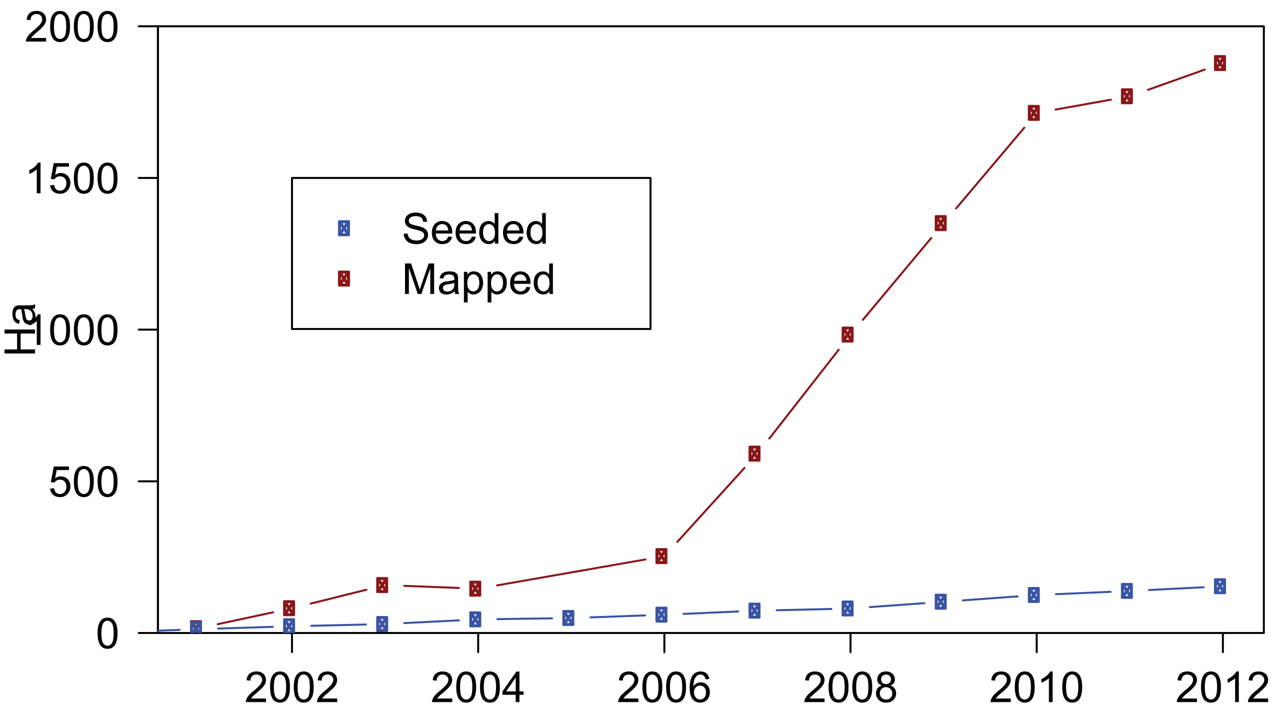
Figure 21. Chlorophyll comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 and 2012 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 1



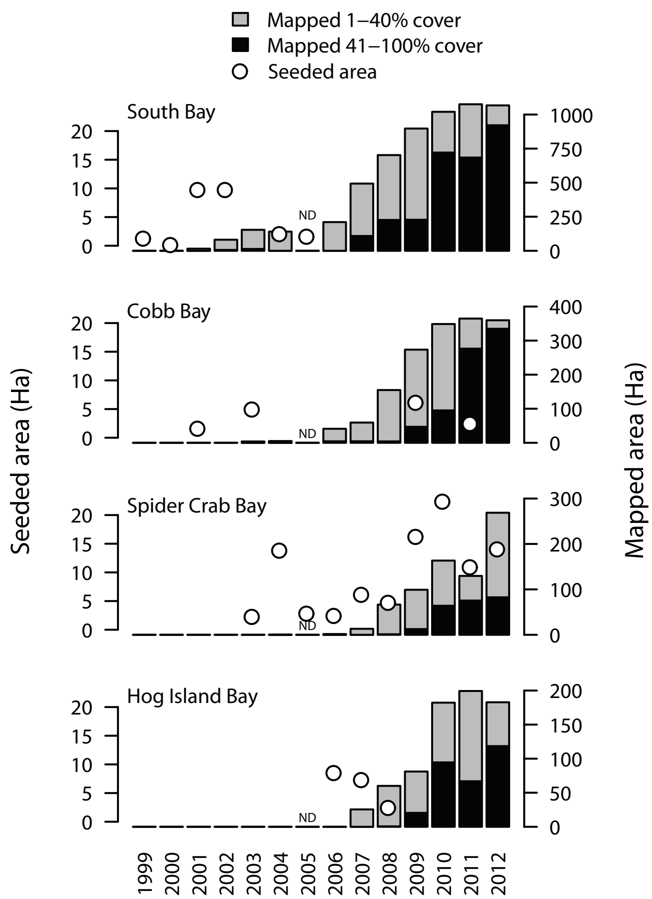
Study Site
0 250 500 Km
Chesapeake Bay
Delmarva Peninsula
Hog Island Bay
Great Machipongo Inlet
Spider Crab Bay
Continuous WQ Station
Cobb Bay
Dataflow Track
Start
Oyster
Sand Shoal Inlet
Continuous WQ Station
South Bay
Atlantic Ocean
0 1 2 3 4 5 6 7 Km
N
37°25'N
37°20'N
37°15'N
76°0'W
75°55'W
75°50'W
75°45'W
75°40'W

Figure 2



2000
1500
1000
500
0
Ha
Seeded
Mapped
2002
2004
2006
2008
2010
2012

Figure 3

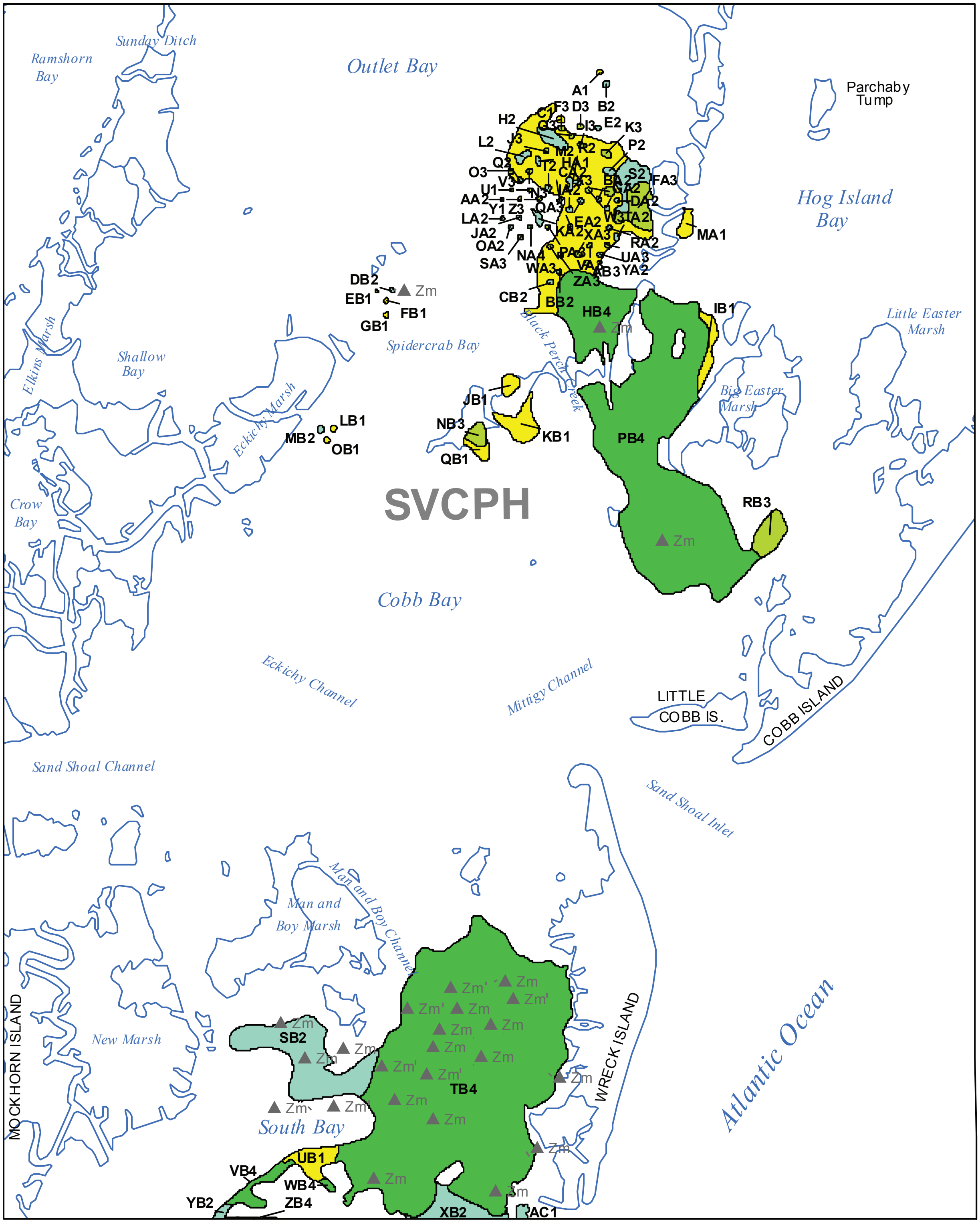


Mapped 1–40% cover
Mapped 41–100% cover
Seeded area
South Bay
Cobb Bay
Spider Crab Bay
Hog Island Bay
ND
Seeded area (Ha)
Mapped area (Ha)
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012

Submerged Aquatic Vegetation 2012

Cobb Island, Va. (184)

Figure 4



Hectares of SAV: 1,322.85
Date Flown: 06/10

1,000 0 1,000 2,000 Meters

2012 SAV Density Class

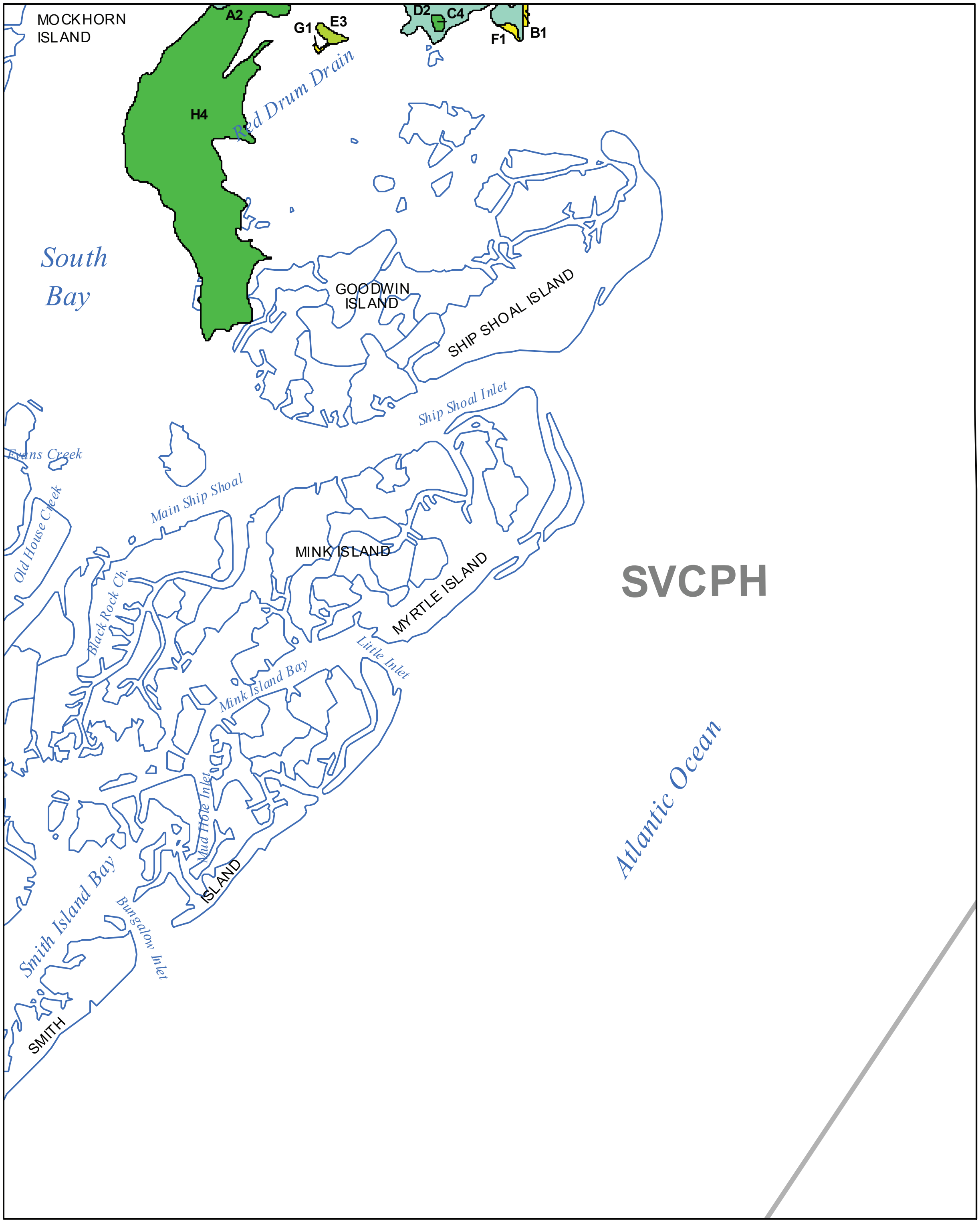
0-10%	10-40%	40-70%	70-100%

Sources: VIMS,USGS **PDF Created:** 10/25/2013

Submerged Aquatic Vegetation 2012

Figure 5

Ship Shoal Inlet, Va. (212)



Hectares of SAV: 372.84
Date Flown: 06/10

1,000 0 1,000 2,000 Meters

2012 SAV Density Class

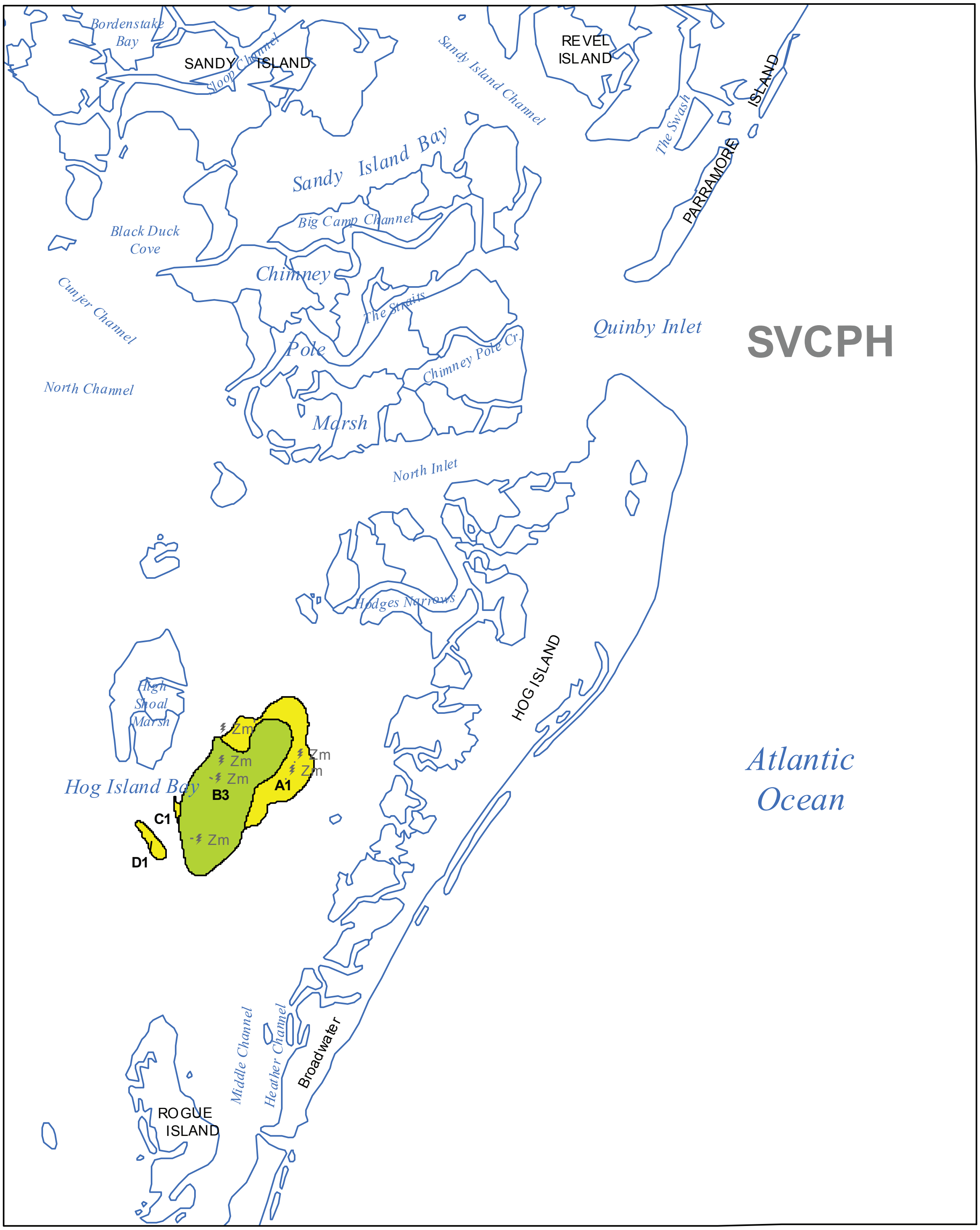
0-10% 10-40% 40-70% 70-100%

Sources: VIMS,USGS **PDF Created:** 10/16/2013

Submerged Aquatic Vegetation 2012

Quinbly Inlet, Va. (215)

Figure 6



Hectares of SAV: 182.78
Date Flown: 06/10

1,000 0 1,000 2,000 Meters

2012 SAV Density Class

0-10% | 10-40% | 40-70% | 70-100%

Sources: VIMS,USGS **PDF Created:** 10/25/2013

Figure 7

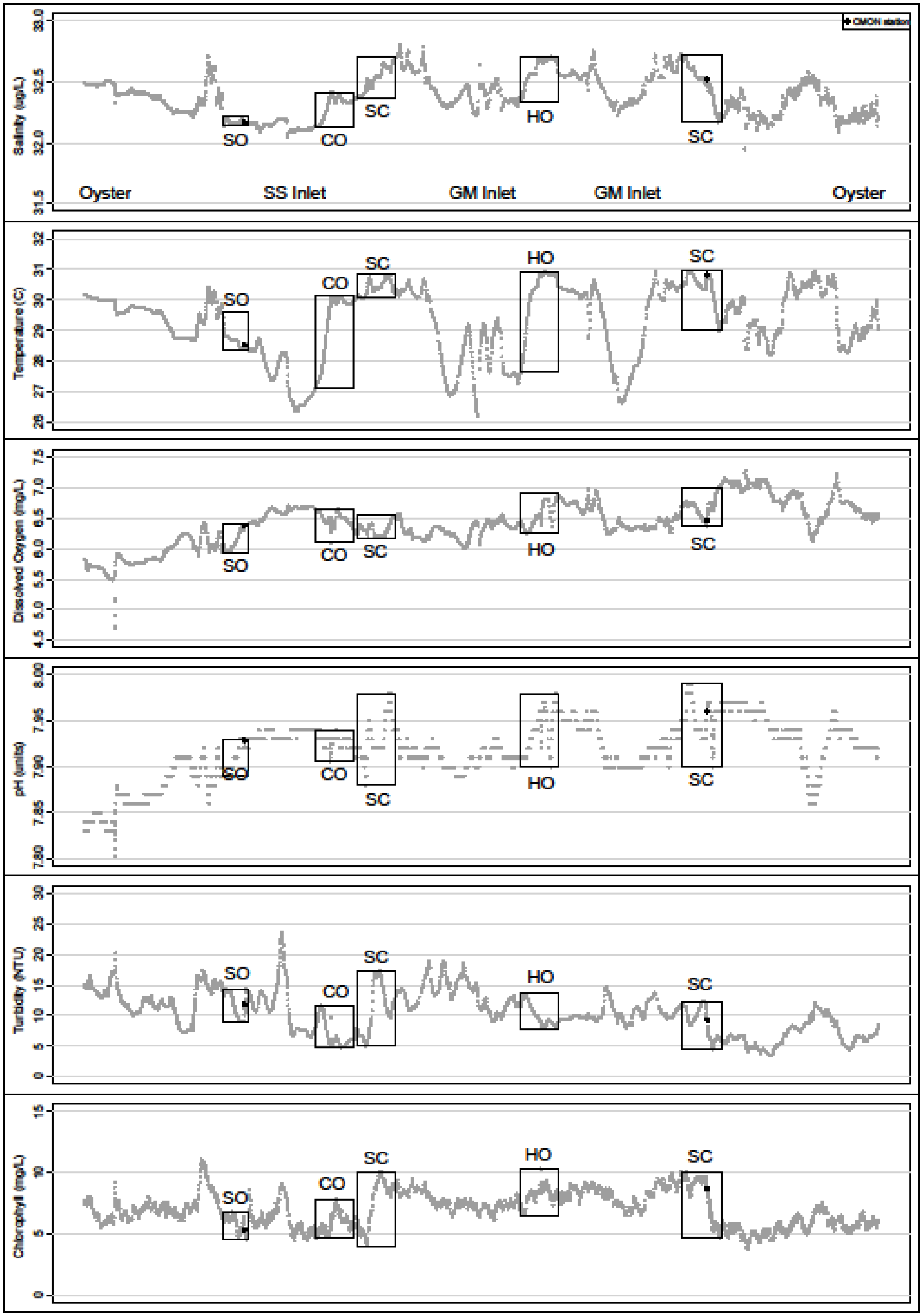


Figure 8

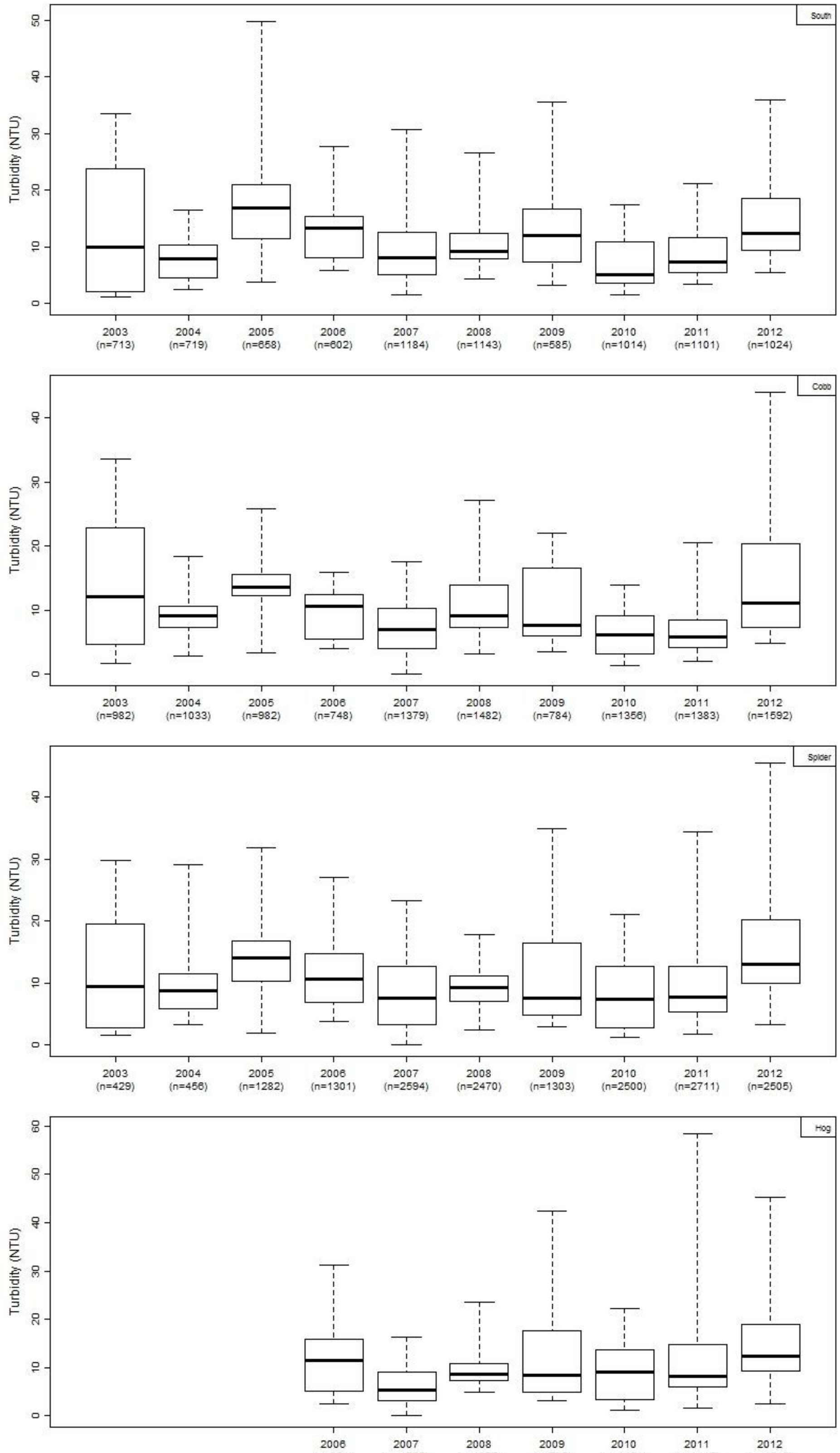

South
Turbidity (NTU)
0
10
20
30
40
50
2003 (n=713)
2004 (n=719)
2005 (n=658)
2006 (n=602)
2007 (n=1184)
2008 (n=1143)
2009 (n=585)
2010 (n=1014)
2011 (n=1101)
2012 (n=1024)
Cobb
Turbidity (NTU)
0
10
20
30
40
2003 (n=982)
2004 (n=1033)
2005 (n=982)
2006 (n=748)
2007 (n=1379)
2008 (n=1482)
2009 (n=784)
2010 (n=1356)
2011 (n=1383)
2012 (n=1592)
Spider
Turbidity (NTU)
0
10
20
30
40
2003 (n=429)
2004 (n=456)
2005 (n=1282)
2006 (n=1301)
2007 (n=2594)
2008 (n=2470)
2009 (n=1303)
2010 (n=2500)
2011 (n=2711)
2012 (n=2505)
Hog
Turbidity (NTU)
0
10
20
30
40
50
60
2006 (n=891)
2007 (n=1592)
2008 (n=1875)
2009 (n=705)
2010 (n=1451)
2011 (n=1417)
2012 (n=1545)

Figure 9

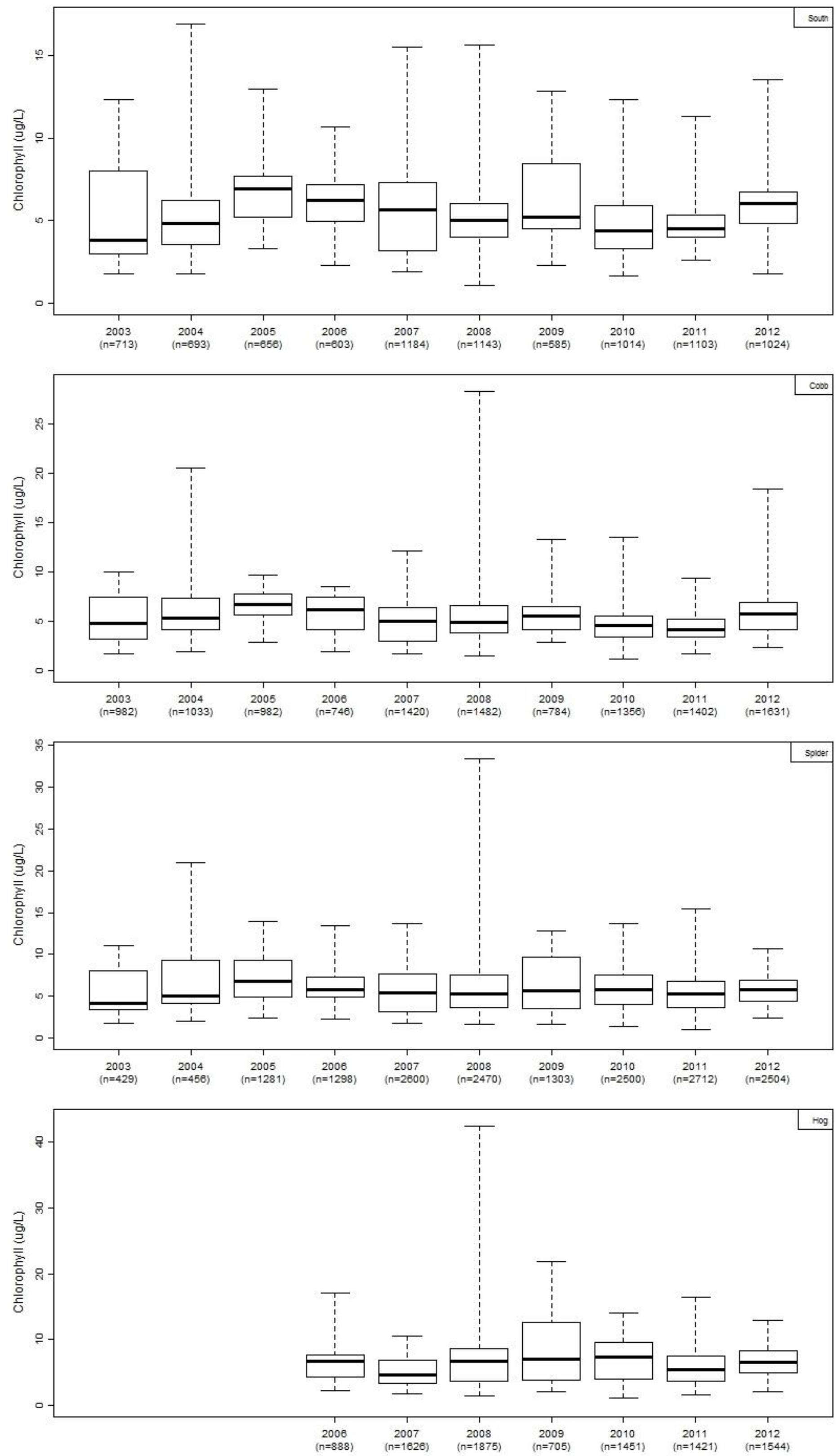
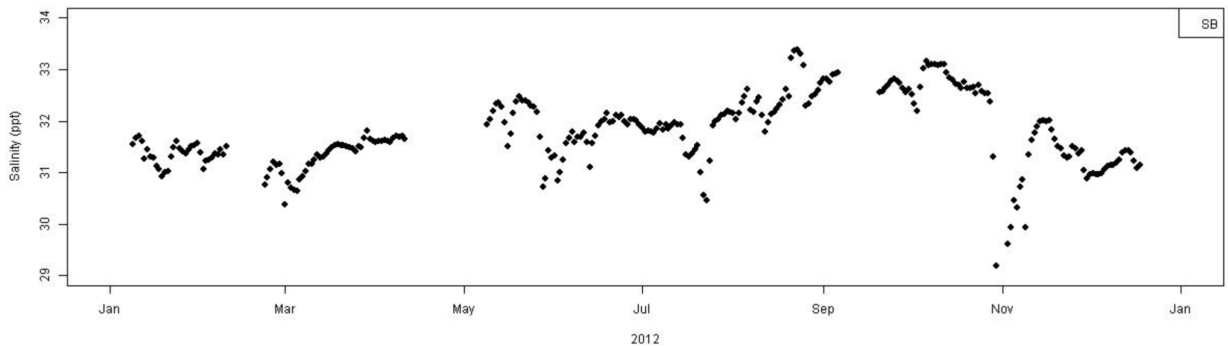

South
Chlorophyll (ug/L)
2003 (n=713)
2004 (n=693)
2005 (n=656)
2006 (n=603)
2007 (n=1184)
2008 (n=1143)
2009 (n=585)
2010 (n=1014)
2011 (n=1103)
2012 (n=1024)
Cobb
Chlorophyll (ug/L)
2003 (n=982)
2004 (n=1033)
2005 (n=982)
2006 (n=746)
2007 (n=1420)
2008 (n=1482)
2009 (n=784)
2010 (n=1356)
2011 (n=1402)
2012 (n=1631)
Spider
Chlorophyll (ug/L)
2003 (n=429)
2004 (n=456)
2005 (n=1281)
2006 (n=1298)
2007 (n=2600)
2008 (n=2470)
2009 (n=1303)
2010 (n=2500)
2011 (n=2712)
2012 (n=2504)
Hog
Chlorophyll (ug/L)
2006 (n=888)
2007 (n=1626)
2008 (n=1875)
2009 (n=705)
2010 (n=1451)
2011 (n=1421)
2012 (n=1544)

Figure 10


SB
Salinity (ppt)
29
30
31
32
33
34
Jan
Mar
May
Jul
Sep
Nov
Jan
2012

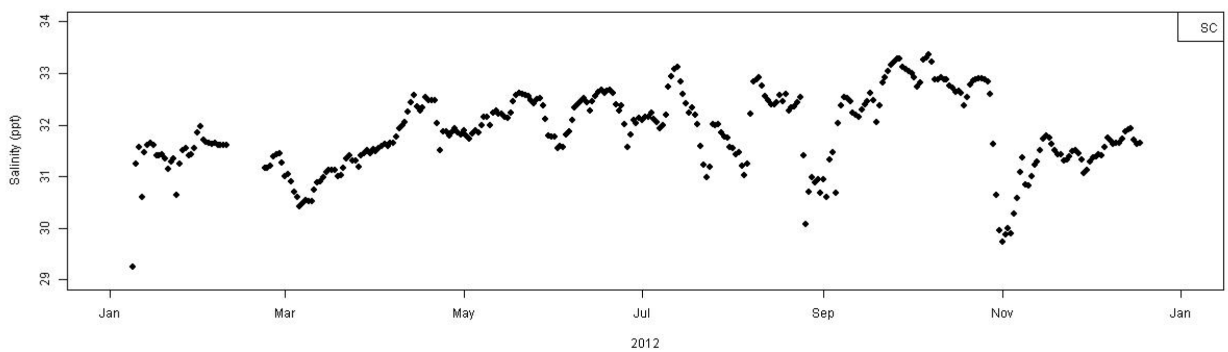

SC
Salinity (ppt)
29
30
31
32
33
34
Jan
Mar
May
Jul
Sep
Nov
Jan
2012

Figure 11

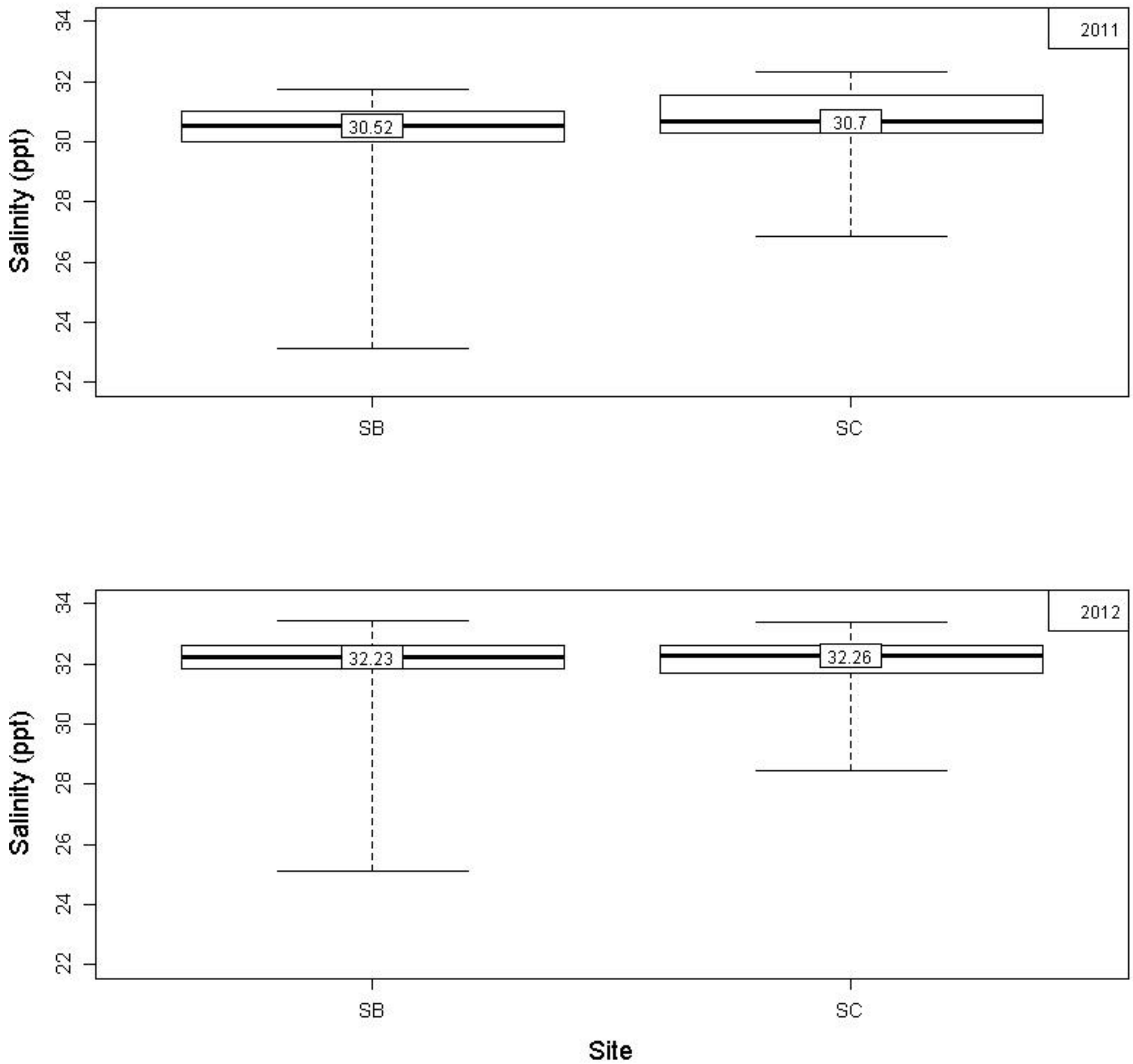
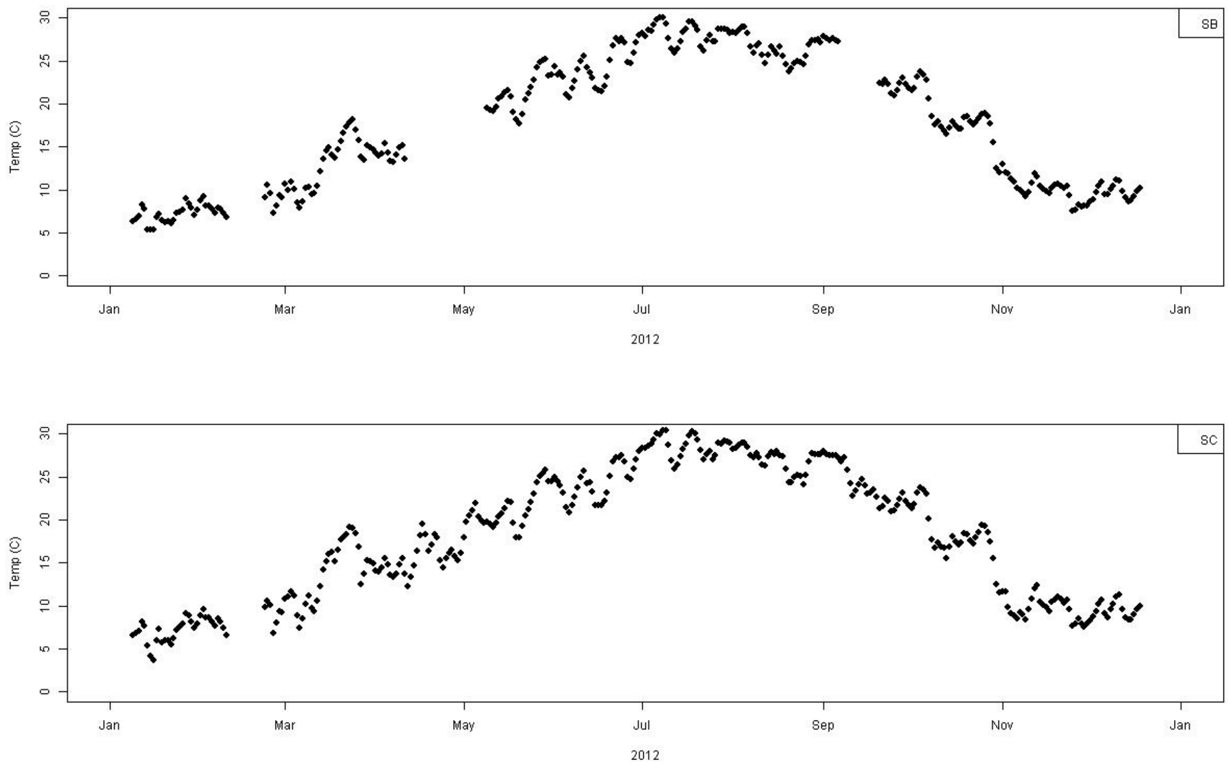
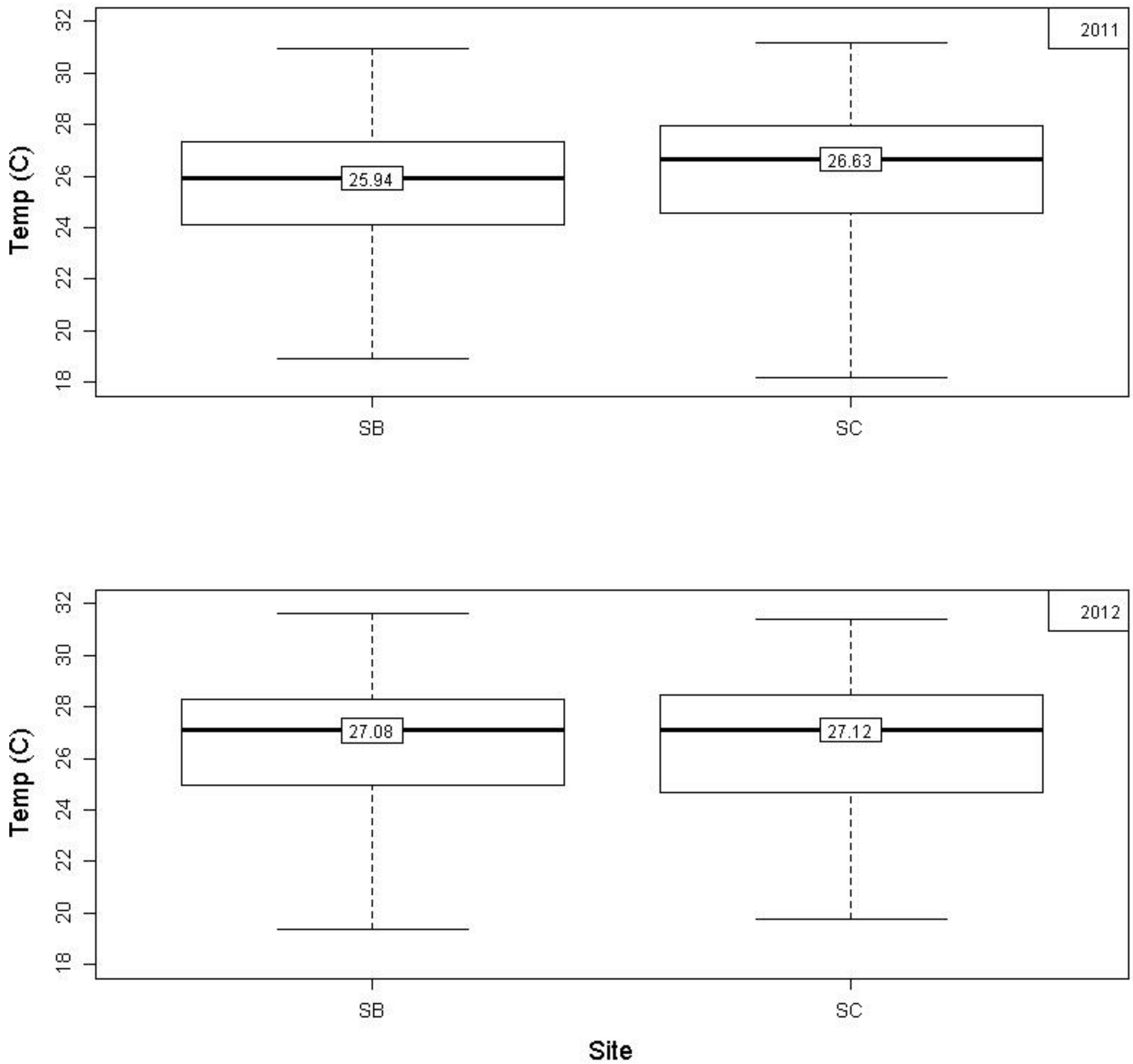

2011
30.52
30.7
Salinity (ppt)
SB
SC
2012
32.23
32.26
Salinity (ppt)
SB
SC
Site

Figure 12



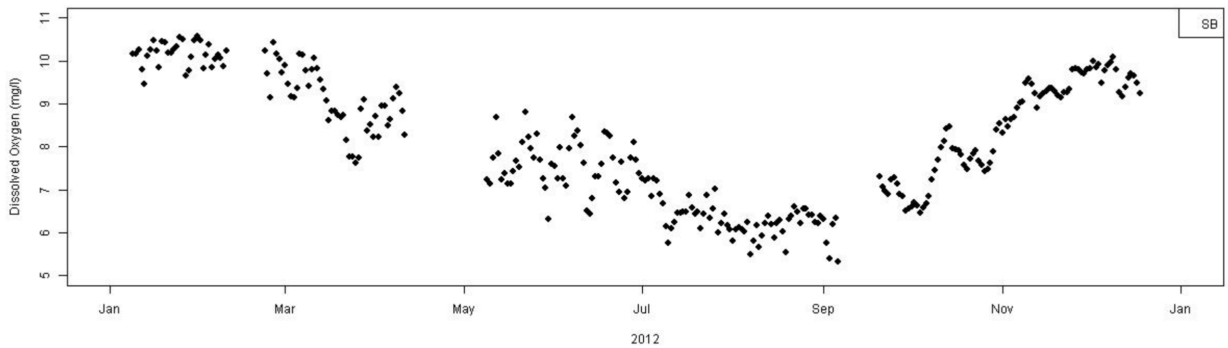
SB
Temp (C)
0
5
10
15
20
25
30
Jan
Mar
May
Jul
Sep
Nov
Jan
2012
SC
Temp (C)
0
5
10
15
20
25
30
Jan
Mar
May
Jul
Sep
Nov
Jan
2012

Figure 13

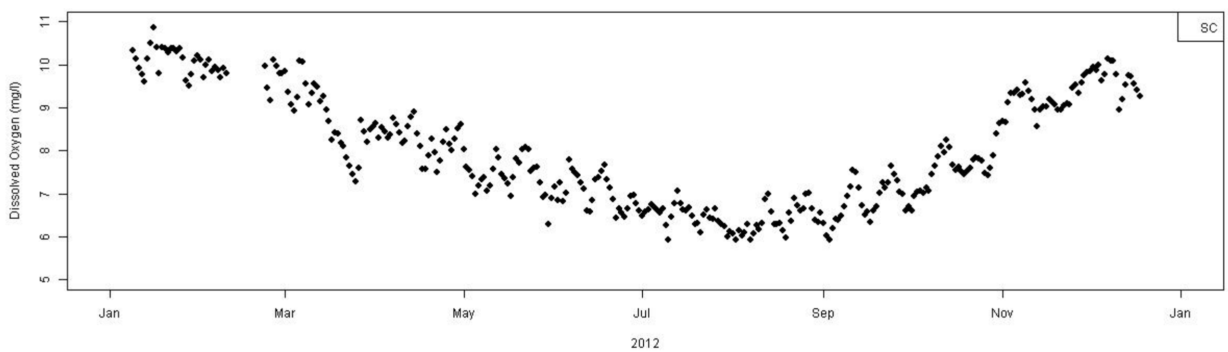


2011
Temp (C)
32
30
28
26
24
22
20
18
25.94
26.63
SB
SC
2012
Temp (C)
32
30
28
26
24
22
20
18
27.08
27.12
SB
SC
Site

Figure 14



SB
Dissolved Oxygen (mg/l)
11
10
9
8
7
6
5
Jan
Mar
May
Jul
Sep
Nov
Jan
2012



SC
Dissolved Oxygen (mg/l)
11
10
9
8
7
6
5
Jan
Mar
May
Jul
Sep
Nov
Jan
2012

Figure 15

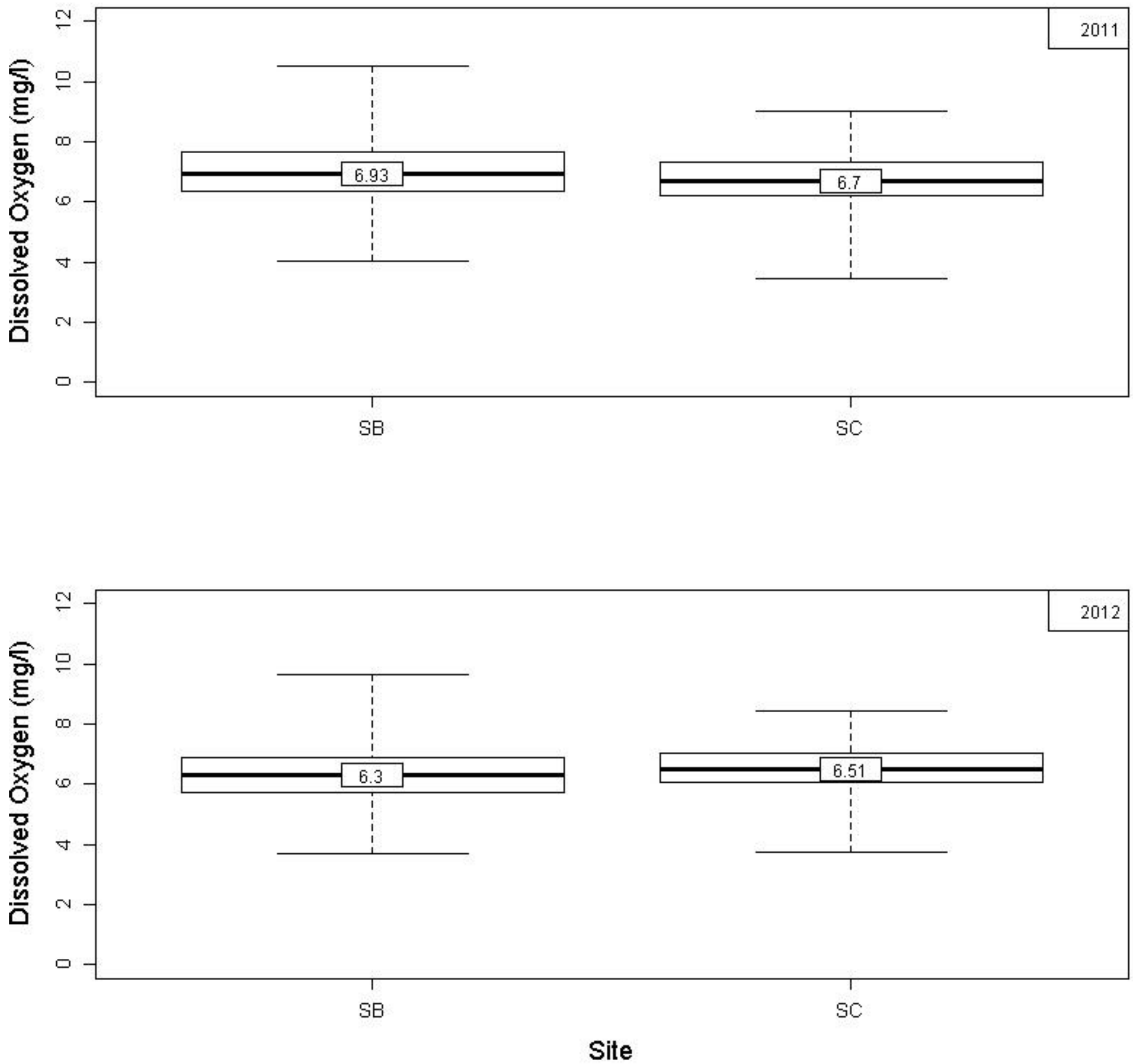

2011
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
6.93
6.7
SB
SC
2012
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
6.3
6.51
SB
SC
Site

Figure 16

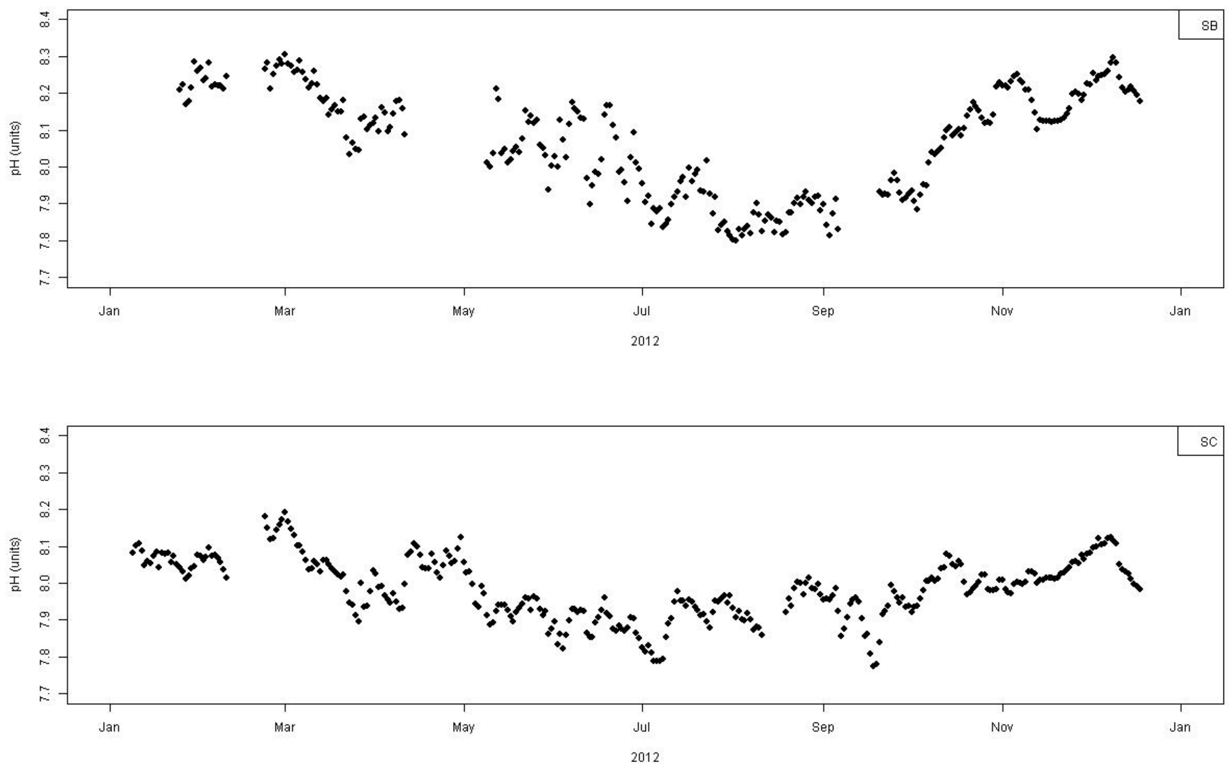
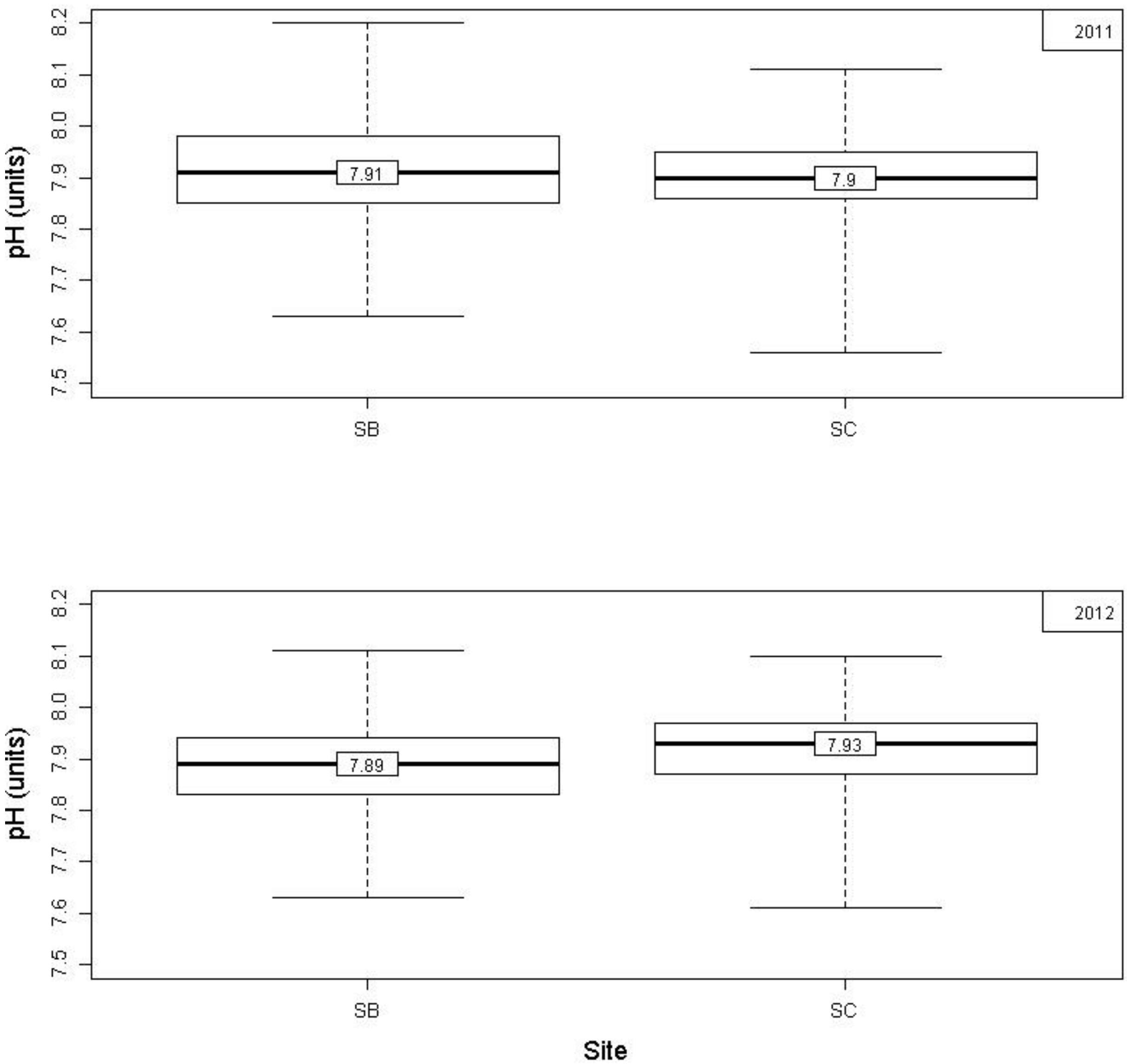

SB
pH (units)
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
Jan
Mar
May
Jul
Sep
Nov
Jan
2012
SC
pH (units)
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
Jan
Mar
May
Jul
Sep
Nov
Jan
2012

Figure 17



2011
pH (units)
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.91
7.9
SB
SC
2012
pH (units)
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.89
7.93
SB
SC
Site

Figure 18

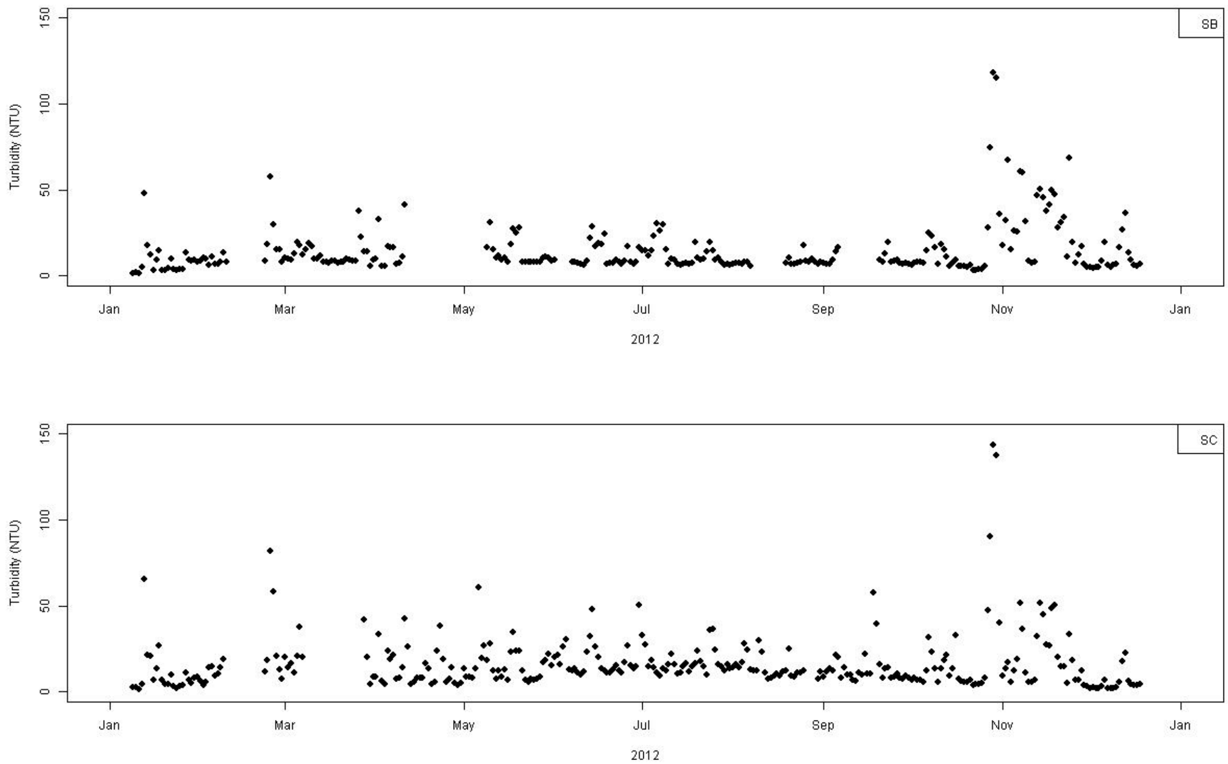
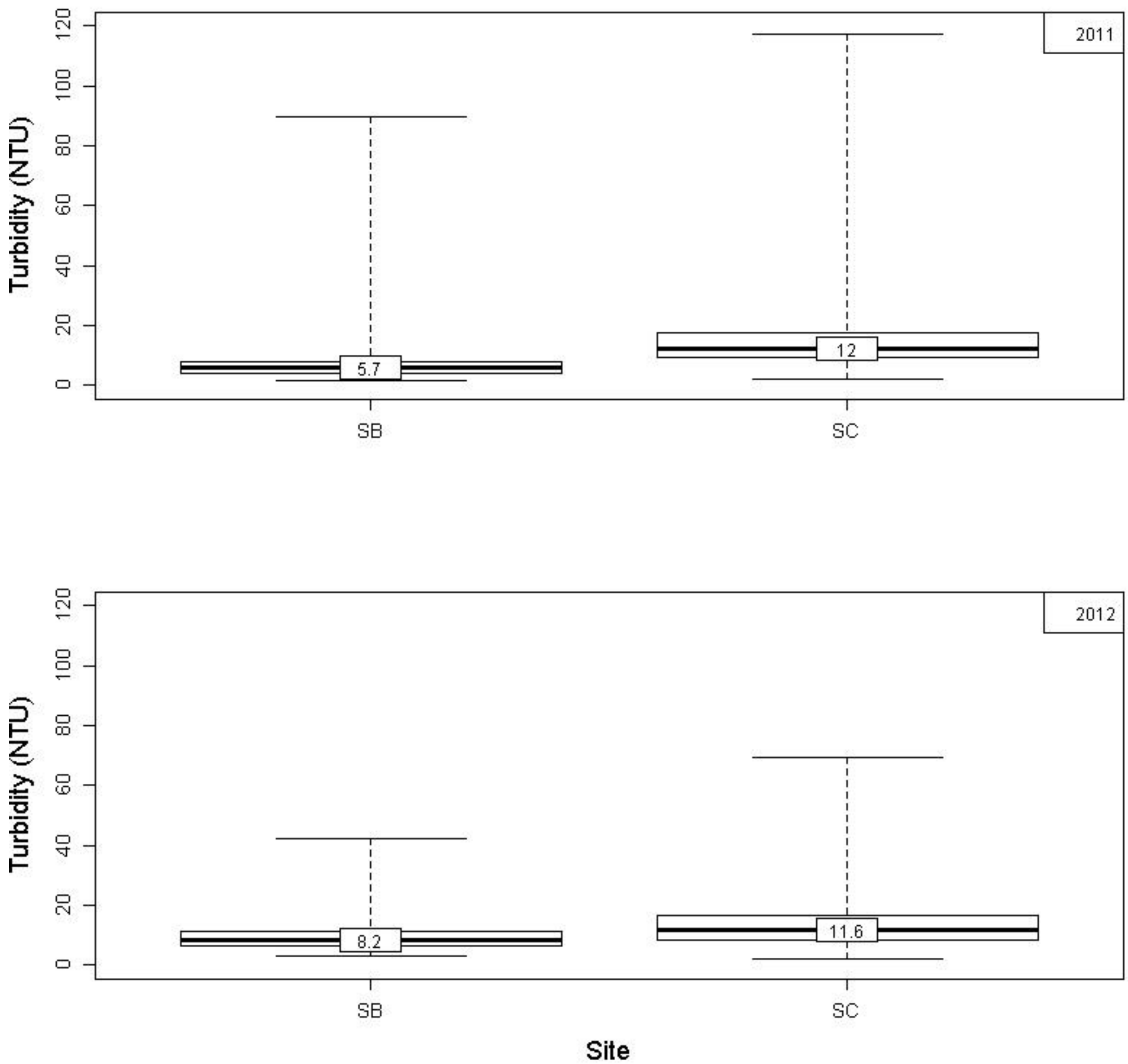
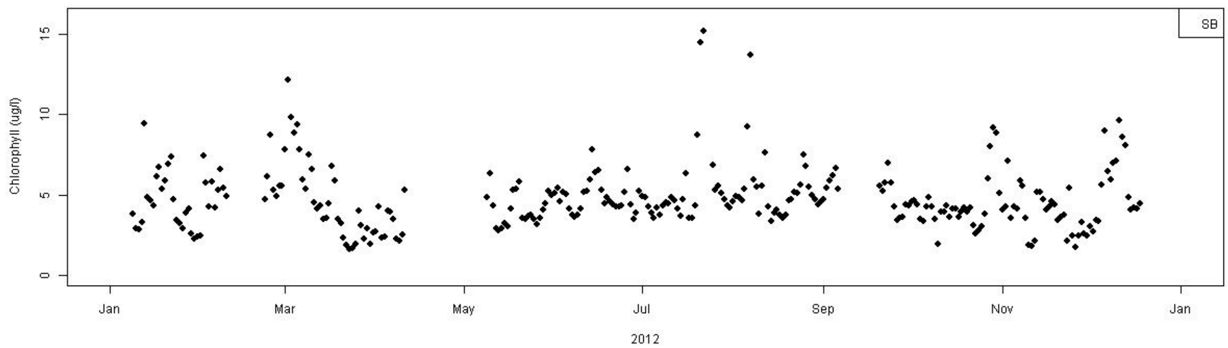

SB
Turbidity (NTU)
0
50
100
150
Jan
Mar
May
Jul
Sep
Nov
Jan
2012
SC
Turbidity (NTU)
0
50
100
150
Jan
Mar
May
Jul
Sep
Nov
Jan
2012

Figure 19

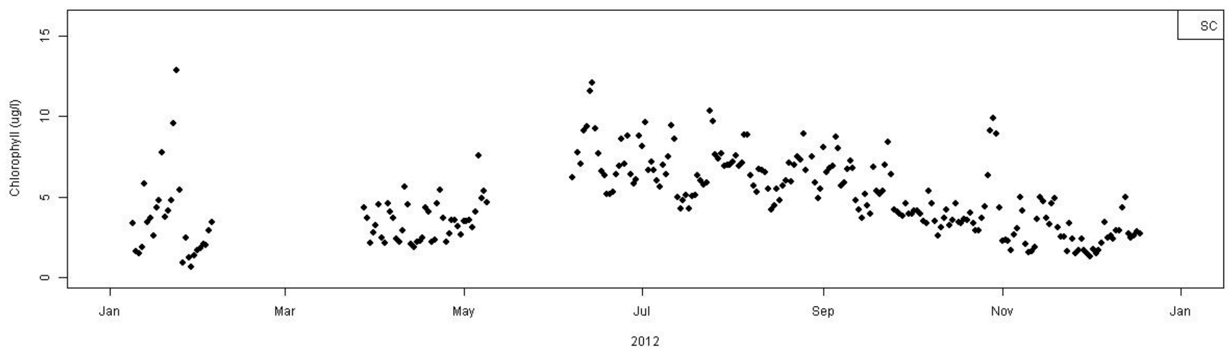


2011
Turbidity (NTU)
0
20
40
60
80
100
120
5.7
12
SB
SC
2012
Turbidity (NTU)
0
20
40
60
80
100
120
8.2
11.6
SB
SC
Site

Figure 20

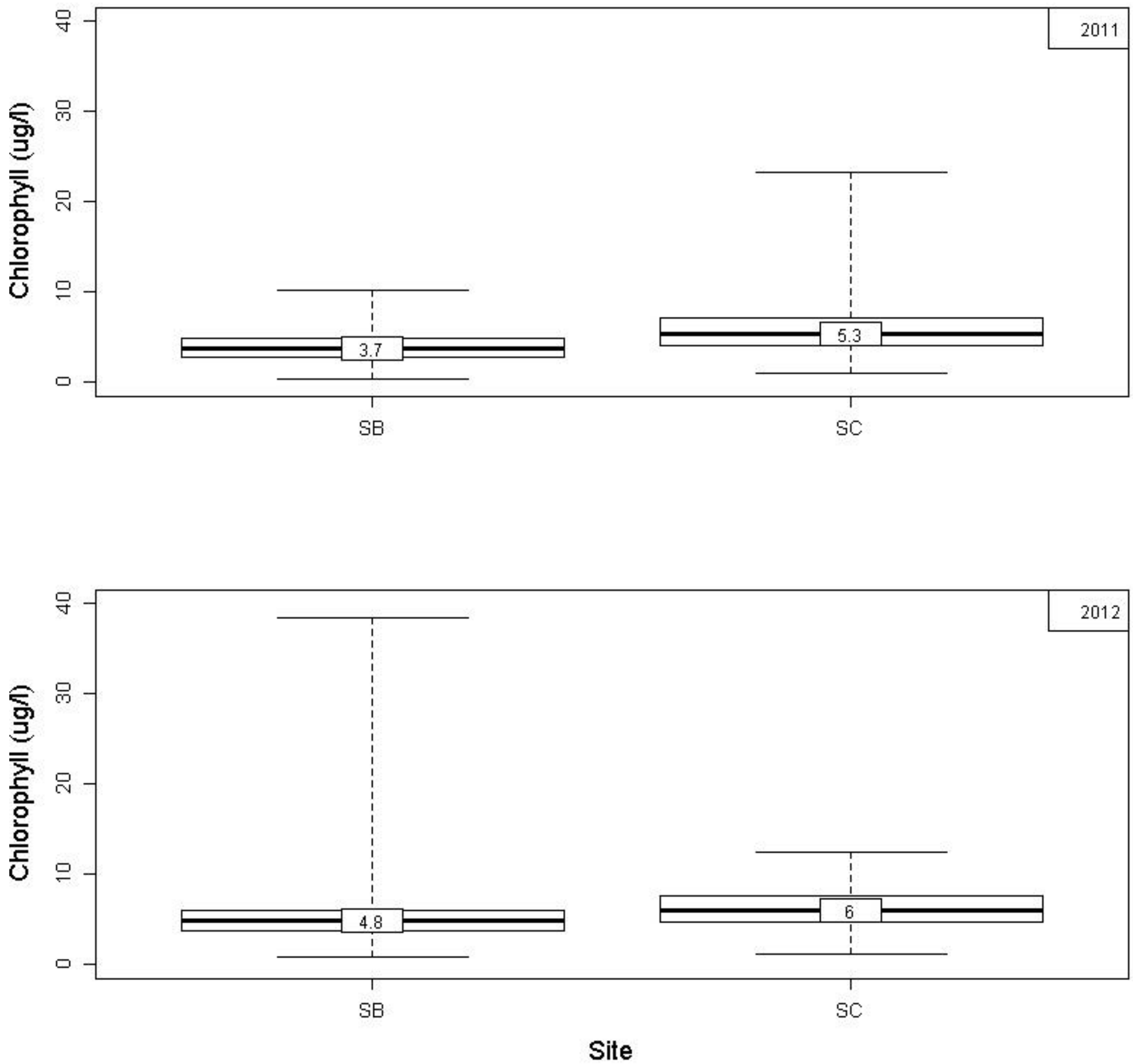


SB
Chlorophyll (ug/l)
0
5
10
15
Jan
Mar
May
Jul
Sep
Nov
Jan
2012



SC
Chlorophyll (ug/l)
0
5
10
15
Jan
Mar
May
Jul
Sep
Nov
Jan
2012

Figure 21



2011
Chlorophyll (ug/l)
40
30
20
10
0
3.7
5.3
SB
SC
2012
Chlorophyll (ug/l)
40
30
20
10
0
4.8
6
SB
SC
Site