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

Nov. 14, 2014

FY2012 Task 12 Eelgrass and Bay Scallop Restoration in the Seaside Bays of Virginia.
(April. 1, 2013, to September 30, 2014)

Robert Orth[1], Kenneth Moore[1], Mark Luckenbach[1], Stephanie Bonniwell[1], Albert Curry, Jr. [1], Sean Fate[1], Frederick Holbert[1], Bo Lusk[2], Scott Marion[1], Betty Neikirk[1], David Parrish[1], Paul Richardson[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

This restoration project was funded, in part, by" the Virginia Coastal Zone Management Program at the Department of Environmental Quality through Grant #NA11NOS4190122 of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, under the Coastal Zone Management Act of 1972, as amended. Matching funds were provided by the Virginia Institute of Marine Science.

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there followed by a significant hurricane in 1933 that likely eliminated the remaining populations (Orth et al. 2006, unpublished data).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 2012 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. Assess eelgrass bed growth and expansion; 4. Enumerate the finfish community that may be potential bay scallop predators; 5. Monitor water quality conditions to assess changes that may be associated with the eelgrass recovery and to identify new potential areas for restoration activities; and 6. Continue bay scallop restoration efforts initiated in 2009 with NOAA’s American Reinvestment and Recovery Act Funds and supported by FY2009, FY2010 and FY2011 Coastal Zone support,

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

2013. 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 (primarily volunteers organized by The Nature Conservancy) or by mechanical harvester in May, 2013, 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 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, 2013, eelgrass seeds were hand broadcast from a boat into pre-determined un-vegetated plots in Spider Crab Bay (Figure 2). Plot size during the 2013 project was 0.4 ha (one acre). Seed density was 200,000 seeds per plot.

Germination rates of seeds collected in 2013 were estimated by planting replicate batches of 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 a re-circulating seawater system 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 and May, 2014, 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

Aerial photography of the coastal bays was not conducted until the fall, 2013, because of weather constraints in the spring. Flight missions were flown both in October and November, 2013, when water clarity improves. However, because eelgrass thins during the fall, identification of sparse beds is difficult to accurately assess. 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 (+/- 60 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 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.

Finfish Sampling
In 2012 and 2013 we conducted annual nekton surveys in South Bay eelgrass beds using a 4.9-m otter trawl towed from a shallow draft vessel at 2300 rpm for 2 minutes, (n = 6). Using GPS start and stop points we have determined that the average tow length was approximately 150-m. Once caught, finfish size and abundance were recorded and then specimens were released. Unidentified specimens were photographed or frozen for subsequent analysis in the laboratory. In 2012 we sampled in the months of July, August, and September. For 2013 we sampled in May, July, August, September, and October.

Data storage, manipulation and summary statistics were performed with Microsoft Excel. Statistical analyses were performed in R (R Core Development Team 2011). The R packages plyr, reshape2, and ggplot2 were used for further data manipulation and plotting. The R package, vegan was used for the non-metric multidimensional scaling (NMDS) and determinations of Shannon diversity to look at the structure, richness and diversity of the finfish communities of the South Bay eelgrass habitat.

Water Quality
Two complementary approaches to documenting water quality conditions were continued in 2013 (Figure 1). Broad spatial patterns in water quality were documented using continuous underway sampling (DATAFLOW) in 2013 as in previous years (this effort commenced in 2003 and has been conducted annually, Orth et al. 2013). 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 2013. Cruises were generally conducted monthly throughout the eelgrass growing season, from March through November, with nine cruises conducted in 2013. While the length of cruise tracks in vegetated and unvegetated areas varied annually as the eelgrass beds developed and expanded, the track in 2013 has encompassed all four bays as it did previously.

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 bay scallops were maintained within a field nursery system and used as brood stock for hatchery spawns to produce offspring for deploying in the seagrass beds in South Bay. All of these scallops originated from parental stock of *Argopecten irradians concentricus* collected from Bogue Sound and Core Sound, North Carolina during 2009, 2010 and 2012, but are now fully integrated to serve as a Virginia broodstock line.

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 (ESL) 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.

The strategy developed over the previous five years has been to grow the juvenile scallops within the field-based nursery until they attain a shell height between 10 – 20 mm then transfer them to larger mesh bags inside bottom cages within the grass beds. Owing to record production of small juvenile scallops during the past year that exceeded the capacity of the field-based nursery, it was necessary to transfer scallops (~ 5 mm in shell height) to small mesh bags for planting within cages in the grass bed.

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 seagrass 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.

Approximately 35,000 adult produced from spawns in spring 2013 were maintained in cages within grass beds in South Bay over the winter. An additional 110,000 juvenile scallops produced from spawns in late summer of 2013 were maintained in the floats in the field-based nursery. Following a particularly cold winter in the region the cages and floats were inspected in March 2014 and surviving scallops were counted and measured.

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 seagrass beds in the coastal bays. Thus, assessing the abundance of wild scallops in the grass beds is of critical importance.

As in previous years in restoration project we utilized a 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 seagrass 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 conducted in 2012, 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.

Using a GIS-based grid overlain on aerial imagery of South Bay, a total of 120 randomly located stations for suction sampling were identified within a 516 hectare (1275 acre) area that comprised most of the grass bed. GPS coordinates were used to locate stations in the field. Samples were then collected, as described above, from each of these locations over a 3-day period in July 2013 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 90 selecting point locations within the grass bed. Each of these 90 locations served as starting points for five haphazardly directed transects. Five separate divers then swam along the transect randomly placing 1 m^2 quadrate and thoroughly search the area within the quadrate, largely by touch as visibility was often poor. Each diver targeted collecting ten quadrates per transect. As with the suction samples, the number of scallops collected per m^2 was multiplied by the area of the grass bed to obtain an estimate of total scallop numbers.

RESULTS

Eelgrass Seeding

In 2013, We had an initial seed count of 12.2 million that were rated as ‘good’ seeds in August but we noted significant mortality in several seed batches in August and September due to a serious fungal infection we could not control that resulted in a final yield of 8.0 million seeds for distribution, 6.0 million designated for the seaside bays. Seeds were broadcast in September into 30 one acre plots in Spider Crab Bay at a seed density of 200,000 seeds per acre (Figure 3). To date 56.8 million seeds have been broadcast into 168.8 ha (417 acres) (Table 1, Figure 3).

Eelgrass Seedling Establishment

Seeding was successful but seedling establishment rates varied among individual plots, bays, and years. The mean seedling establishment rate for all evaluated plots seeded in 2013 was 1.15% (range of 0 – 6.3%). 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 2013 areal measurements was available for the South Bay grassbeds only. Detection of grassbeds in the other beds was compromised by water clarity issues at the time of the acquisition of the photography. In 2013 we mapped 3527 acres, an increase of 890 acres from what was recorded in South Bay in 2012, with approx. 70% of the entire bed considered dense

(Figure 4). Ground assessments conducted in May and June, 2014, confirmed the presence of eelgrass in these new areas. Figure 5 shows a composite of grass bed changes in South Bay in 2001, 2004, 2007, 2010, and 2013.

Finfish

Due to a few dominant taxa, total abundance was highest in the summer months, most notably in July (Figure 6). The top four most abundant fishes in order across all samples were pinfish, silver perch, (Figures 7a and b) pigfish, and then spot. Abundances were much lower in the spring and fall months.

Finfish surveys in South Bay yielded a β richness of 19 taxa so far (Table 2). The differences in sample (α) species richness and sample diversity as a function of month (Figure 8).

Water Quality

Figure 9 presents the yearly integrated, median, 25% and 75% quadrille, maximum and minimum of the turbidity levels recorded by the DATAFLOW cruises across each of the four restoration areas for the entire 2003-2013 restoration study period. In 2013 turbidity levels dropped considerably in all the bays compared to 2012. Median levels were below 10 NTU at all the sites during 2013 in contrast to 2012 when median levels were above 10. Chlorophyll concentrations in 2013 (Figure 10) were also considerably below 2012 with median concentrations below 5 µg/l at all sites.

Daily mean salinities measured at the South Bay and Spider Crab Bay restoration site monitoring stations for 2013 are compared to 2012 measurements in Figure 11 varied between 29 and 33 with highest levels observed from June to September at both sites. During August daily mean salinities approached 34 in South Bay. Median salinities were similar between the sites although the range in South Bay was slightly less than Spider Crab Bay (Figure 12). Slightly higher median levels were recorded overall in both bays in 2013 compared to 2012, which in turn were higher than 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 13). Overall, median summertime water temperatures in 2013 were approximately 1.5-2.0 °C lower in 2013 than 2012 at both sites (Figure 14). The trend of slightly cooler water temperatures at South Bay than Spider Crab Bay measured in earlier years continued throughout 2013.

Dissolved oxygen concentrations followed similar seasonal trends to 2012 with lowest values observed during the warmest summertime periods (Figure 15). Mean levels never fell below 5 mg^{-1} demonstrating that these areas 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 16). Median concentrations were higher in 2013 compared to 2012 and were very comparable to 2011.

pH levels were well buffered and ranged between 7.8 and 8.4 with levels generally highest in the late winter (Figure 17). Median summertime levels were nearly identical between the restoration sites and similar during 2011, 2012 and 2013 (Figure 18) although slightly higher concentrations in 2013 at South Bay paralleled slightly higher dissolved oxygen concentrations.

Turbidity levels in both restoration sites were seasonally highest in July (Figure 19). Both sites continued to demonstrate similar periods of short-term turbidity increases, especially the fall. These short term increases were likely related to storm and other wind events. Median summer concentrations in South Bay were overall much lower in South Bay compared to Spider Crab Bay, especially during the summer (Figure 20). Previous studies here have shown 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. So far the trend of reduced turbidity over time is not evident in Spider Crab Bay where the restored seagrass beds are much less abundant. Turbidity conditions in 2013 at South Bay were much better than in 2012 suggesting much clearer water throughout the growing season.

Chlorophyll concentrations remained generally low (< 10µg-1) although high concentrations were measured in February and March when blooms appeared for several weeks at both restoration sites (Figure 21). Other episodically high levels were most likely related to re-suspension of phyto-benthos. Median concentrations in the summer were similar between 2011 and 2013 although 2012 showed higher median concentrations at both sites (Figure 22). 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 such as South Bay.

Scallop Seed Production

Two spawns were conducted during the late summer of 2013. The first of these spawns yielded 1.98 million late-stage larvae that were placed into the land-based nursery. Four weeks later 110,000 juveniles from this group were placed in the field-based nursery where they will be reared until early spring 2014 when they will be transferred cages in the grass bed for spawning. The second spawn on Sept. 10, 2013 yielded 1.56 million late-stage larvae. Declining water temperatures at this time of the year result in lower growths, making the nursery phase impractical. Thus, all 1.56 million larvae were released directly into the grassbed in South Bay, where owing to lower predation rates in the fall they are expected to experience good survival and contribute to the wild spawning stock in 2014.

66,000 of the 110,000 juvenile scallops that were overwintered in the field-based nursery survived until the next spring. The 60% survival rate in the field-based nursery through the winter is below the 75% survival that is typically observed through this phase and likely reflects a particularly cold winter in the region. These scallops were placed in the South Bay seagrass bed in April 2014.

Three separate scallop spawns were conducted in the research hatchery at the ESL on May 8, 13 and 16, 2014 which yielded 2.7 million, 0.2 million and 3.0 million larvae, respectively, at the end of the culture period. Better than usual survival through the land-base nursery stage resulted in the production of over 700,000 juvenile scallops coming out of that stage. Previous efforts have yielded 1 – 5% survival during this very sensitive stage, so the 11% survival achieved during this phase of the project represents a significant increase. This number of juvenile scallops exceeded the capacity of field-based nursery system so they were transferred to fine-mesh bags in cages in the South Bay grassbed on July 1 – 2, 2014, where the intent is to grow them in cages until fall 2014 when predation predator abundances decrease and then release the majority into the grass bed, while maintaining sufficient numbers to fill our spawning stock cages.

Maintenance of Scallop Spawning Stocks in Grass beds
Approximately 66,000 scallops produced during summer 2013 spawns were maintained in cages in the grassbed through the summer of 2014 and the cages and bags were cleaned as necessary. These animals were expected to spawn during the late summer to early fall of 2014. The 700,000 scallops produced during the spring of 2014 were also placed in grassbed and will be maintained as described above.

Assessment of Wild Population
Quantitative sampling of the wild scallops in the grass bed in South Bay in July, 2013, using diver surveys for large scallops (>15mm) and suction sampling for smaller scallops (<15 mm) resulted in an estimated wild population of approximately 202,000 scallops in the grass bed (173,400 0 – 1 year-olds and 28,600 1 – 2 year-olds). The estimate of new recruits in 2013 (the 0 – 1 year class) is approximately an order of magnitude lower than the estimated new recruits in 2012 (see Table 1) and may be the result of the fewer brood stock deployed in the grass bed during spring 2013 than in the previous year. The greater numbers of scallops deployed in the grassbed during 2014 should reverse this trend in future years and lead to an increase in the wild scallop population.

DISCUSSION

Eelgrass Bed Development
The use of seeds in the recovery of eelgrass in the Virginia coastal bays continued successfully in 2013. 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. While we experienced significant seed mortality in 2013, something we had not seen before, we still had 8.0 million viable seeds, of which 6.0 million were distributed into 30 one acre plots in Spider Crab Bay in 2013. Spider Crab Bay was targeted for continued restoration given that the spread of eelgrass has been slower here than in South and Cobb bays.

While we were only able to obtain aerial imagery for South Bay in2013, the increase here over 2012 was indeed impressive, with 360.3 ha (890 acres) more in 2013. Most of the increase occurred in the southern portion of South Bay approaching Mockhorn Island (Figure 5). We even noted small sparse beds around Ship Shoal Channel, as well as near Running Channel, areas we did not expect to see any growth. The size of the patches noted in the photography indicated they were more than one year old. and thus were undoubtedly present in 2012, and perhaps earlier, but were too small to be detected by the aerial photography.

Finfish
Pinfish were very abundant in the summer samples and this trend of higher pinfish numbers mirrors what Sobocinski et al. (2013) found with her recent analysis of Chesapeake Bay eelgrass faunal dataset when compared to a historic dataset. Pinfish are abundant in seagrass beds south of Chesapeake Bay and are found in Chesapeake Bay but at very low densities. Their high abundances in 2013 may be a result of warmer spring temperatures in 2013 allowing movement of this species from southern grass beds. Pinfish have been shown to be major predators on amphipod mesograzers (Stoner 1979) which leads to a depression of the epifaunal community when they are abundant. Implications for these changes in fish community species composition could have implications for grazer populations which are known to reduce epiphytic populations, which at high levels can shade eelgrass and lead to eelgrass loss (Duffy et al. 2005).

We found that overall South Bay fish richness peaked in the summer, however due to the disproportionately high abundance of the dominant species in the summer months the distribution was not very even, therefore the Shannon diversity peaks in the fall when, even though richness is lower. This is a good indication that in the cooler months a variety of fish species in the community are more evenly distributed.

Based on the β and ϒ species richness of nearby Chesapeake Bay eelgrass fish communities (S=40) as seen in Sobocinski et al. (2013), it remains to be seen what our rarefied (Sanders, 1968) species richness will be for this eelgrass habitat. It should become clear with time and more samples where the overall ϒ diversity of the fauna in the South Bay restoration grass bed stands. The various diversity components (α, β and ϒ) will be parsed out with future sampling based on the methods of deBello et al. (2010). This will allow us to have an understanding of the phylogenetic and functional as well as the taxonomic diversity of the South Bay eelgrass bed and others like it.

Water Quality in the Virginia Coastal Bays
Water quality monitoring in 2013 indicates that, overall, water quality remained high for eelgrass growth and restoration in all of the coastal lagoon areas studied here. Both turbidity and phytoplankton concentration in 2013 were lower than those observed in 2012 indicating improved light conditions for eelgrass growth. In 2013 salinities were higher and water temperatures lower throughout the system than in 2012. Both of these conditions are supportive of eelgrass growth. Overall 2013 appeared to have very good water quality conditions for eelgrass growth and expansion. The higher salinity and cooler water suggests these area may be receiving offshore water to a greater extent in 2013 compared to 2012. South Bay continued to show slightly better water quality than Spider Crab Bay, and water clarity, as measured as turbidity continued to improve in South Bay. This may be attributed to the greater areas of restored eelgrass vegetation here. This will improve water quality through increased baffling of waves and currents leading to increased particle settling and reduced re-suspension of recently deposited bottom sediments. The capacity of these and eelgrass beds to improve water quality conditions for their growth is well evident in these coastal bay restoration sites since the restoration project commenced. Overall, our monitoring in 2013 continued improvement in water quality conditions that which will lead to further eelgrass habitat expansion and recovery from historic declines in the 1930s.

Scallop Restoration

Our final report for the previous phase of this work (FY2011 Task 12 Eelgrass and Bay Scallop Restoration in the Seaside Bays of Virginia, Oct. 1, 2011, to March 31, 2013) discussed the strategy that had emerged from our first 4 years of scallop restoration. We will not repeat all of the strategy elements here, but note that we identified the dual approach of (a) rearing spring (and sometimes late summer) spawns of scallops in cages in the grassbed through spawning time the following spring and (b) rearing fall spawned scallops only to the stage that they can be free planted in the grass bed prior to winter. We noted that our early success—as indicated by a wild population of approximately 2 million scallops resulting from the planting of about 100 thousand broodstock in the grassbed—provided a proof of concept for this strategy. Results from this past phase in the restoration, though disappointing in total numbers, reinforce this proof of concept. We estimate that only about 35,000 caged broodstock were in the grassbed during the spawning time that would have produced juvenile scallops in our summer 2013 population census. Despite this downturn in population size, we are encouraged by the very significant increases that we have achieved in production of new scallops during this project period and expect to see that result in an increase in wild scallop estimates in future years

Acknowledgments

We appreciate the numerous staff and students, who made the success of this project possible, notably Jim Goins, Steve Snyder, Paige Ross, Stephanie Benwitz, Erika Schmitt, AJ Johnson, Steve Manley, 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 Nature Conservancy, as well as private grants from Norfolk-Southern, and the Keith Campbell Foundation for the Environment.

LITERATURE CITED

de Bello F, Lavergne S, Meynard CN, Leps J, Thuiller W (2010) The partitioning of diversity: showing Theseus a way out of the labyrinth. J. of Veg Science 21:992-1000

Dobson JE, Bright EA, Ferguson RL, Field DW, Wood LL, Haddad KD, Iredale H, III, Jensen JR, Klemas VV, Orth RJ, Thomas JP (1995) NOAA Coastal change analysis program (C-CAP): Guidance for regional implementation. NOAA Tech. Rep. NMFS 123. 92pp

Duffy JE, Richardson JP, France KE (2005) Ecosystem consequences of diversity depend on food chain length in estuarine vegetation. Ecology Letters 8:301-309.

Marion SR, Orth RJ (2010) Innovative techniques for large scale collection, processing, storage, and dispersal of eelgrass (*Zostera marina*) seeds. Restor Ecol 18:514-526

McGlathery KJ, Reynolds L Cole LW, Orth RJ, Marion SR, Schwarzchild A (2012**)** Recovery trajectories in a temperate system restored by seeding. Mar Ecol Prog Ser 448:209-221

Moore KA, Orth RJ, Nowak JF (1993) Environmental regulation of seed germination in *Zostera marina* L. (eelgrass) in Chesapeake Bay: Effects of light, oxygen and sediment burial. Aquat Bot 45:79-91

Orth RJ, Luckenbach MW, Moore KA (1994) Seed dispersal in a marine macrophyte: Implications for colonization and restoration. Ecology 75:1927-1939

Orth RJ, Luckenbach ML, Marion SR, Moore KA, Wilcox DJ (2006) Seagrass recovery in the Delmarva Coastal Bays, USA. Aquat Bot 84:26-36

Orth, R. J. and K. J. McGlathery. (2012). Eelgrass recovery in the coastal bays of the Virginia Coast Reserve, USA. Mar Ecol Prog Ser 448 173-176

Orth RJ, Moore KA, Marion SR, Wilcox DJ, Parrish DB (2012) Seed addition facilitates eelgrass recovery in a coastal bay system. Mar Ecol Prog Ser 448:177-195

Orth RJ, Wilcox DJ, Nagey LS, Owens AL, Whiting JR, Kenne AK (2010) Distribution of Submerged Aquatic Vegetation in the Chesapeake Bay and Coastal Bays - 2009. VIMS Special Scientific Report Number 149. Final report to U.S. EPA Chesapeake Bay Program, Annapolis, MD

R Development Core Team (2011) *R: A Launguage and Environment for Statistacl Computing, R Foundation for Statistical Computing.* Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Sanders, HL (1968) Marine Benthic Diversity: A Comparative Study. The American Naturalist, 102:243-282.

Sobocinski KL, Orth RJ, Fabrizio MC, Latour RJ (2013) Historical comparison of fish community structure in lower Chesapeake Bay seagrass habitats. Estuaries and Coasts DOI 10.1007/S12237-013-9586-3

Stoner AW (1979) Species-specific predation on amphipod crustacean by pinfish *Lagodon rhomboids*: Mediation by macrophyte standing crop. Mar. Biol. 55:201-207

Table 1. Summary of eelgrass seed distributions for all four bays (number of viable seeds distributed, total area seeded, size and number of plots seeded).

	South Bay				Cobb Bay			
Year	Seeds x 106	Area (ha)	Plot size (ha)	n plots	Seeds x 106	Area (ha)	Plot size (ha)	n plots
1999	0.3	1.2	0.6	2				
2000	0.6	0.1	0.0	9				
2001	3.6	9.7	0.4	24	0.6	1.6	0.4	4
2002	1.8	9.7	0.4	24				
2003					1.1	4.9	0.2	24
2004	0.7	2	2.0	1				
2004								
2005	0.5	1.6	0.2	8				
2006								
2006								
2007								
2007								
2008								
2009					2.3	6.1	0.4	15
2010								
2011					1.1	2.4	0.4	6
2012								
2013								
Total	7.5	24.3		68	5.0	15.0		49

	Spider Crab Bay				Hog Island Bay			
Year	Seeds x 106	Area (ha)	Plot size (ha)	n plots	Seeds x 106	Area (ha)	Plot size (ha)	n plots
1999								
2000								
2001								
2002								
2003	0.5	2.2	0.2	11				
2004	0.6	1.6	0.2	8				
2004	5.9	11.8	0.8 - 2	7				
2005	1.0	2.8	0.2	14				
2006	0.5	2.4	0.2	12	0.6	2.8	0.2	14
2006					1.2	5.7	0.4	14
2007	1.5	6.1	0.2	30	0.5	2.4	0.2	12
2007					0.9	4.9	0.4	12
2008	1.2	4.7	0.2	23	0.6	2.4	0.4	6
2009	6.0	16.2	0.4	40				
2010	5.5	22.3	0.4	55				
2011	2.0	10.9	0.4	27				
2012	7.3	14.2	0.4	35				
2013	6.0	12.1	0.4	30				
Total	38.0	107.3		292	3.8	18.2		58

Table 2. Species list of fauna collected during the trawl period from 2012 to 2013.

Common Name	Species	total
Atlantic Silverside	*Menidia menidia*	60
Black Seabass	*Centropristis striata*	22
Conger eel	*Conger oceanicus*	1
Southern stingray	*Dasyatis americana*	1
Dusky Pipefish	*Syngnathus floridae*	18
Gag Grouper	*Mycteroperca microlepis*	19
Northern Pipefish	*Syngnathus fuscus*	34
Pigfish***	*Orthopristis chrysoptera*	132
Pinfish*	*Lagodon rhomboides*	454
Planehead filefish	*Stephanolepis hispida*	1
Puffer	*Sphoeroides maculatus*	1
Red drum	*Sciaenops ocellata*	1
Sheepshead	*Archosargus probatocephalus*	29
Silver Jennie	*Eucinostomus gula*	5
Silver Perch**	*Bairdiella chrysoura*	305
Spot****	*Leiostomus xanthurus*	128
Spottail pinfish	*Diplodus holbrookii*	2
Summer Flounder	*Paralichthys dentatus*	3
Tautog	*Tautoga onitis*	2
Toadfish	*Opsanus tau*	2

*most abundant, **second most abundant, ***third most abundant, and **** fourth most abundant

Table 3. Area and % of the grassbed sampled by each method and the resulting estimate of juvenile and adult scallop abundances by year.

Year	Area (and %) of grassbed sampled with suction sampler	Estimated # juv. scallops	Area (and %) of grassbed sampled by divers	Estimated # adult scallops
2012	108 m^2 (0.003%)	1,970,000	1748 m^2 (0.05%)	47,000
2013	114 m^2 (0.002%)	173,400	4500 m^2 (0.09%)	28,600

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. Map of Spider Crab Bay showing location of each of the 30 plots that were seed in 2013.

Figure 3. Cumulative area of seeding and total area estimate from the aerial mapping for all four seaside bays through 2013 (Note – area data for the 4 bays were unavailable for 2013 – see report text for the explanation).

Figure 4. Area of seeding in each of four bays (left axis), and area mapped in two density classes by aerial photography each year (right axis). (Note – in 2013, seeds were only broadcast in Spider Crab Bay while areal measurements were only available for South Bay).

Figure 5. Map of South Bay showing eelgrass distribution in 2001, 2004, 2007, 2010 and 2013.

Figure 6. Total fish abundance/trawl for the months of May (05) through October (10) for 2012 and 2013. Shaded area shows the 95% CI about the mean (green line).

Figure 7a. Abundance of pinfish per trawl over the course of the survey period from May through September for 2012 and 2013. Shaded area shows the 95% CI about the mean (orange line).

Figure 7b. Abundance of silver perch per trawl over the course of the survey period from May through September for 2012 and 2013. Shaded area shows the 95% CI about the mean (blue line).

Figure 8. Species richness (right) versus Shannon diversity index (left). Shaded area shows the 95% CI about the mean (line).

Figure 9. 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 2003-2013.

Figure 10. 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 2003-2013.

Figure 11. Daily mean salinity concentrations at South (SB) and Spider Crab (SC) Bays. January –December 2012 - 2013.

Figure 12. Salinity comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 - 2013. (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 13. Daily mean water temperatures at South (SB) and Spider Crab (SC) Bays. January – December 2012-2013.

Figure 14. Water temperature comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 - 2013 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 15. Daily mean dissolved oxygen concentrations at South (SB) and Spider Crab (SC) Bays. January –December 2012-2013.

Figure 16. Dissolved oxygen comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 - 2013 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 17. Daily mean pH concentrations at South (SB) and Spider Crab (SC) Bays. January – December 2012 - 2013.

Figure 18. pH comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 - 2013 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 19. Daily mean turbidities at South (SB) and Spider Crab (SC) Bays. January –December 2012 - 2013.

Figure 20. Turbidity comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 - 2013 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 21. Daily mean chlorophyll concentrations at South (SB) and Spider Crab (SC) Bays. January –December 2012 – 2-13.

Figure 22. Chlorophyll comparisons at South (SB) and Spider Crab (SC) Bays for July-September 2011 - 2013 (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data).

Figure 1

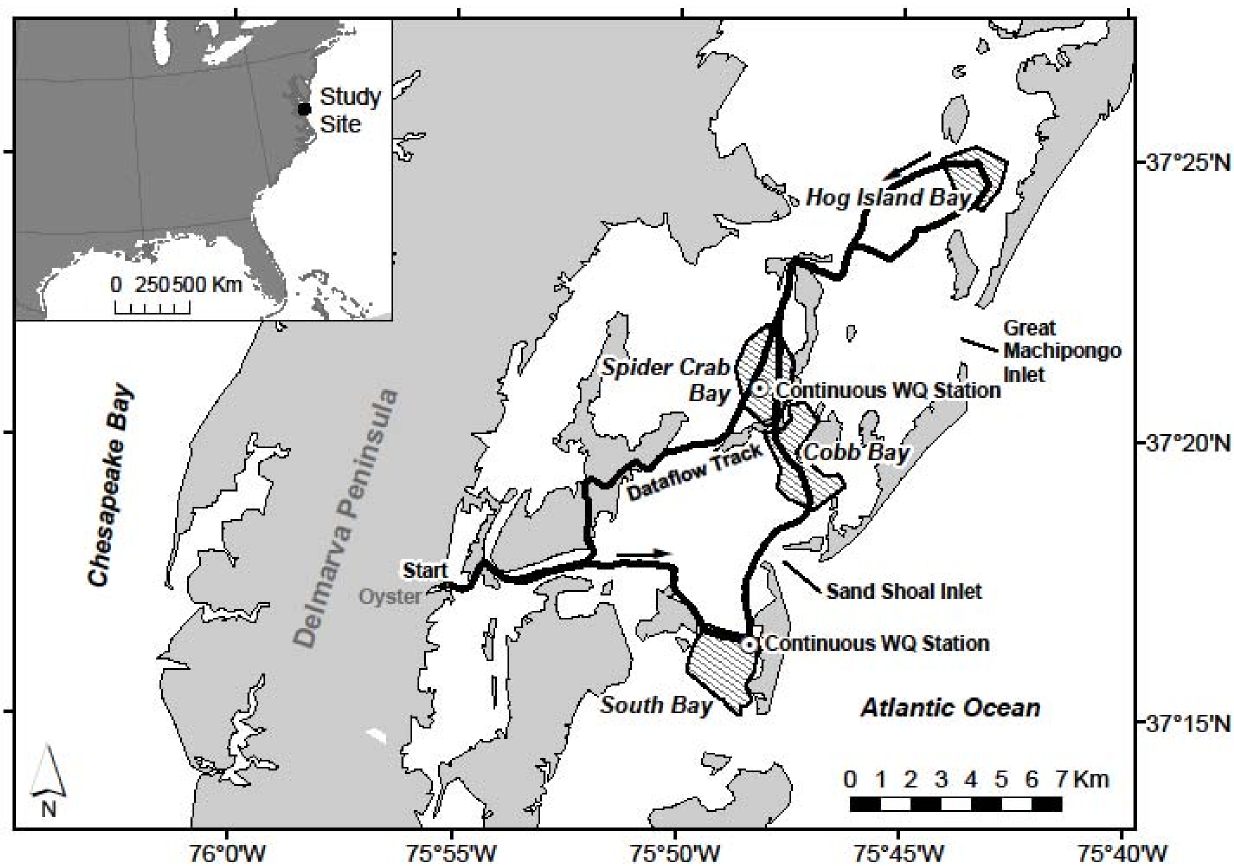

Study
Site
0 250 500 Km
Chesapeake Bay
Delmarva Peninsula
Hog Island Bay
Great
Machipongo
Inlet
Spider Crab
Bay
Continuous WQ Station
Cobb Bay
Dataflow Track
Start
Oyster
Sand Shoal Inlet
Continuous WQ Station
South Bay
Atlantic Ocean
0 1 2 3 4 5 6 7 Km
N
37°25'N
37°20'N
37°15'N
76°0'W
75°55'W
75°50'W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

Figure 2

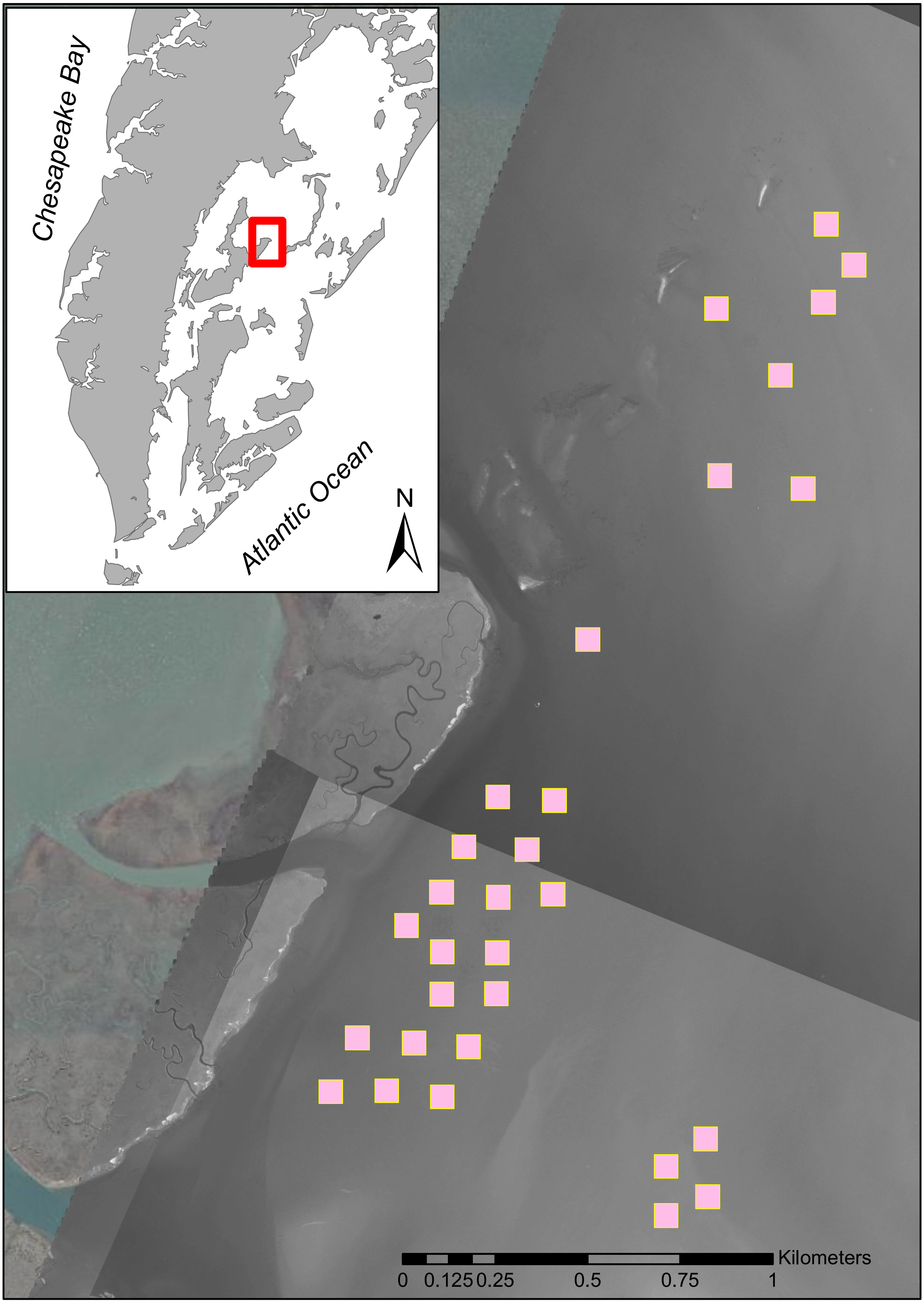
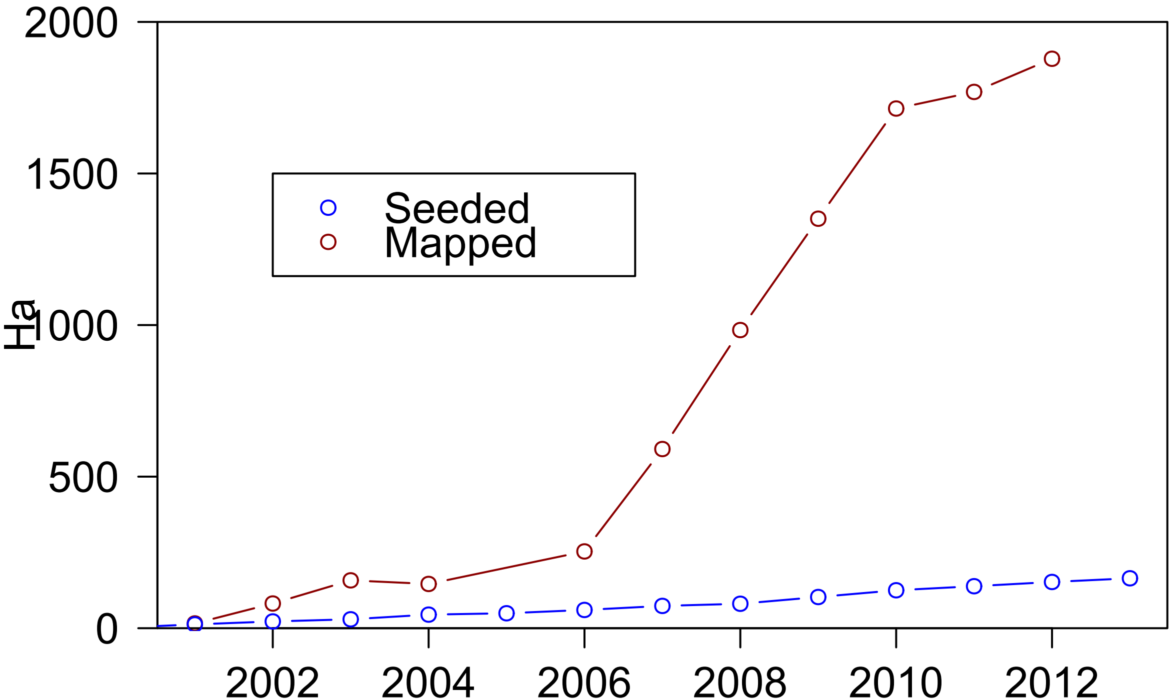
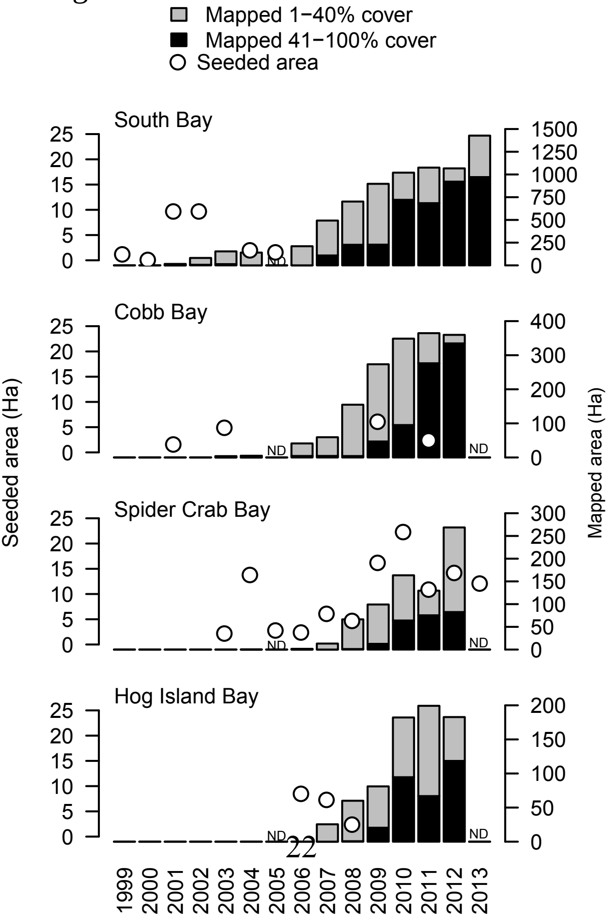

Chesapeake Bay
Atlantic Ocean
N
Kilometers
0
0.125
0.25
0.5
0.75
1

Figure 3



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

Figure 4



Mapped 1−40% cover
Mapped 41−100% cover
Seeded area
South Bay
Cobb Bay
Spider Crab Bay
Hog Island Bay
Seeded area (Ha)
Mapped area (Ha)
ND
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

Figure 5

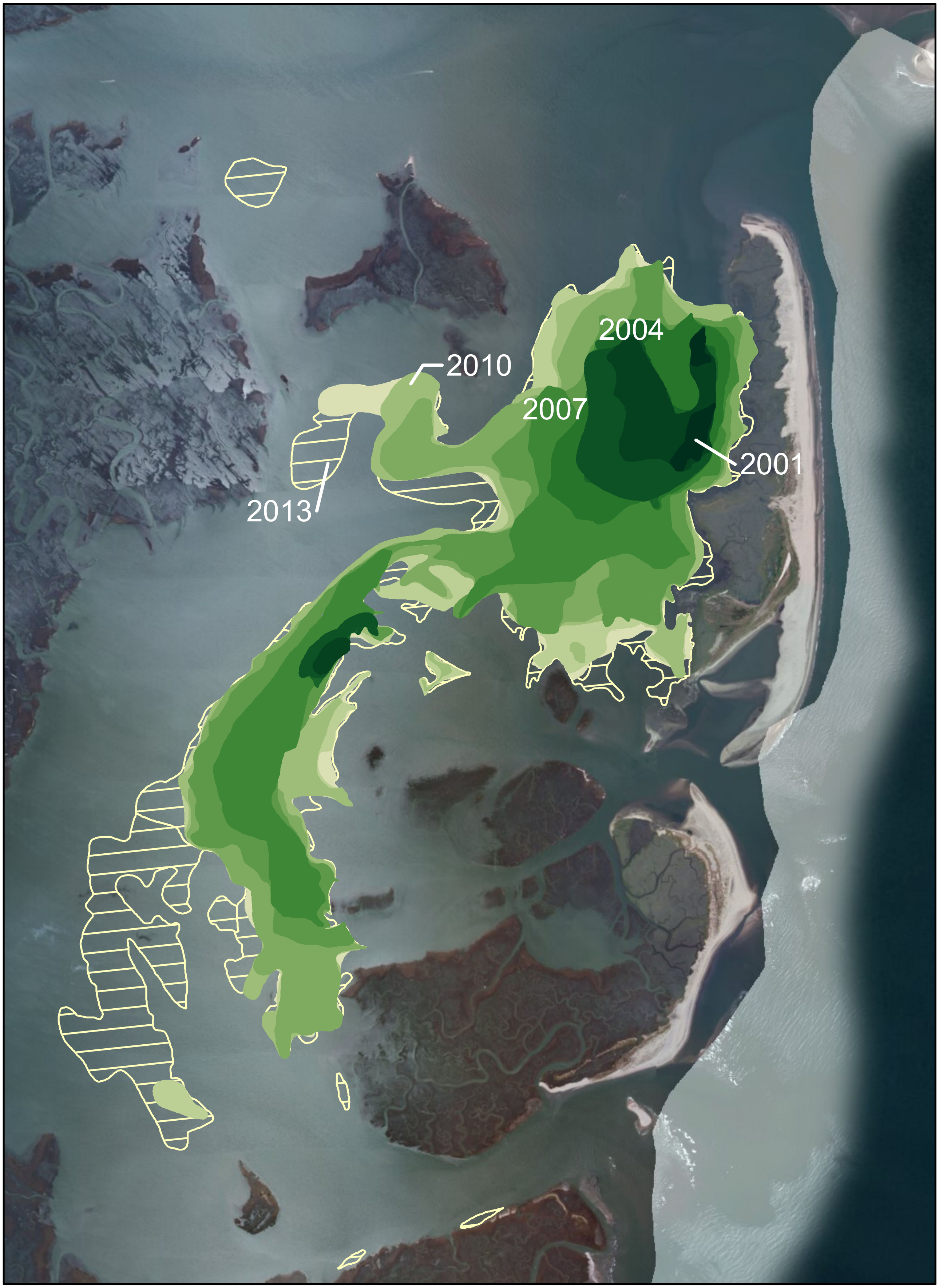
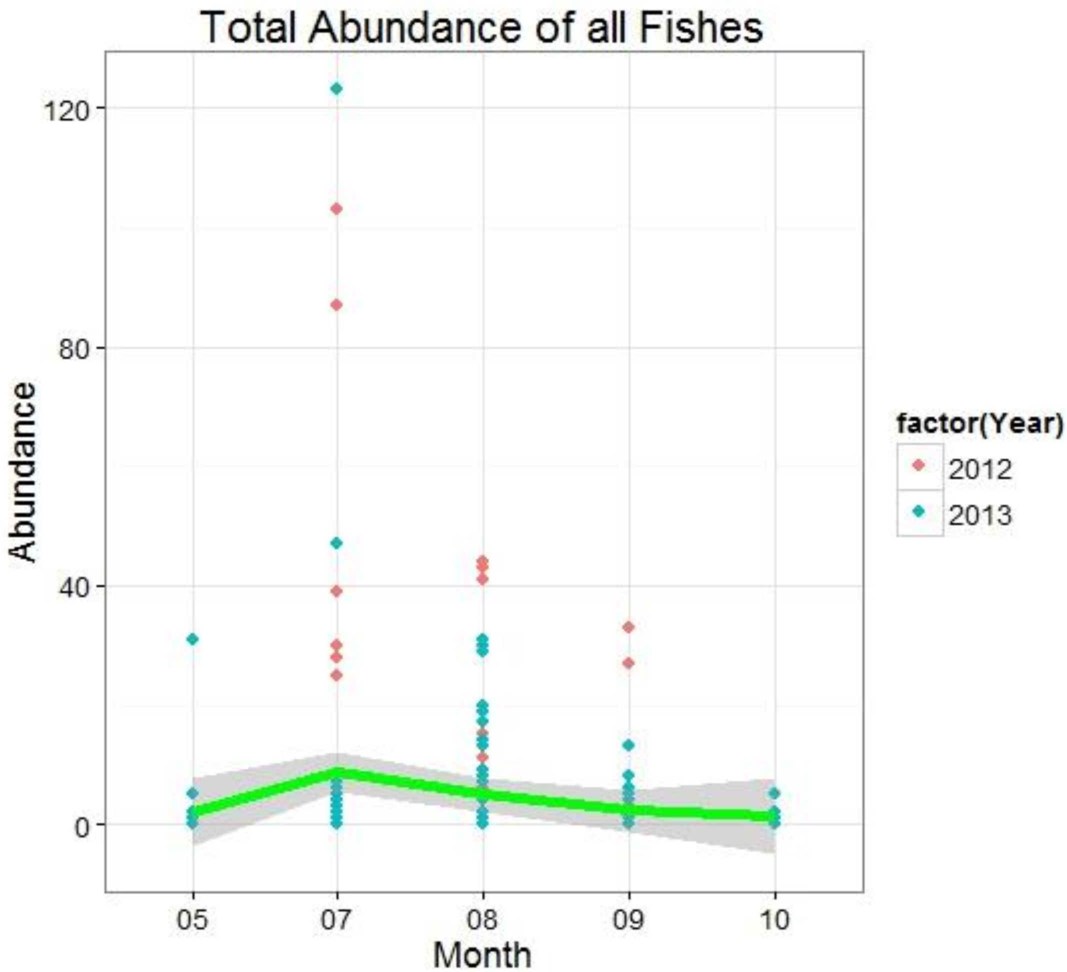
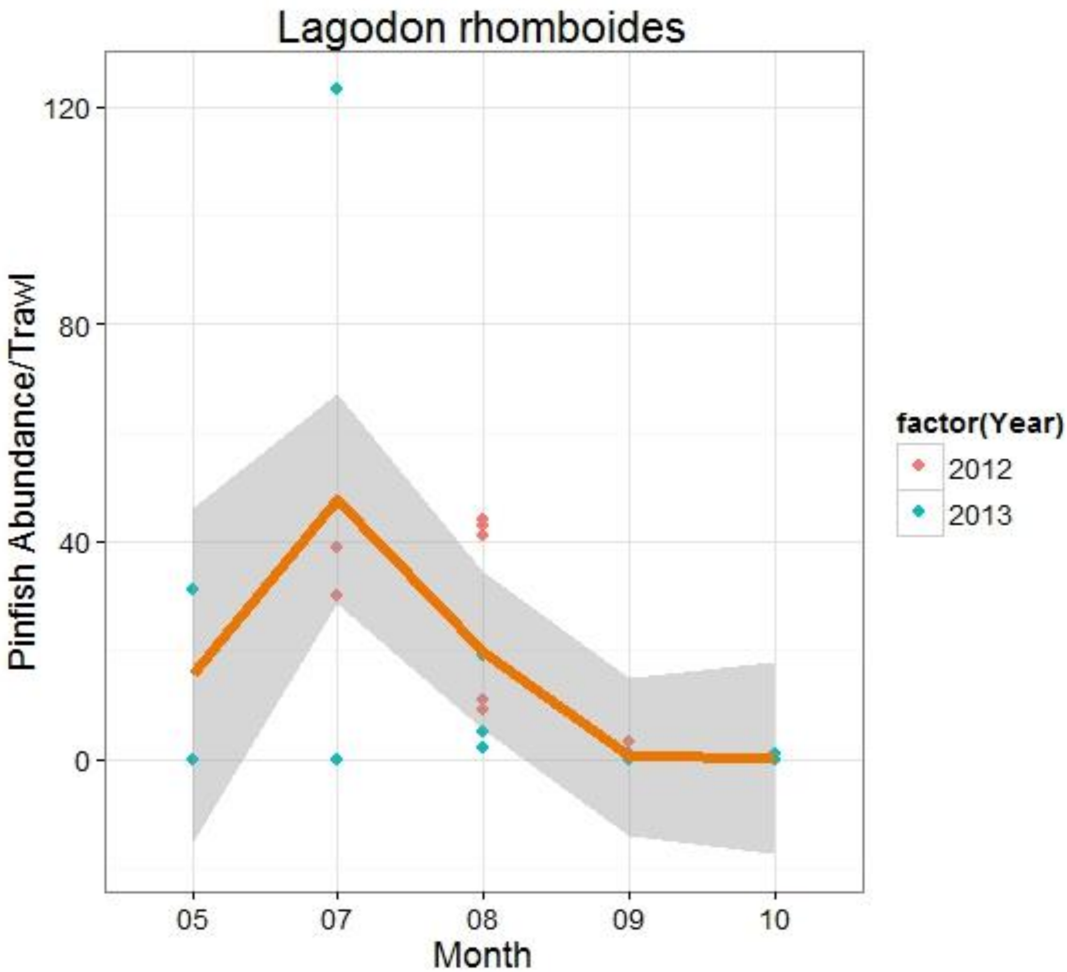


Figure 6



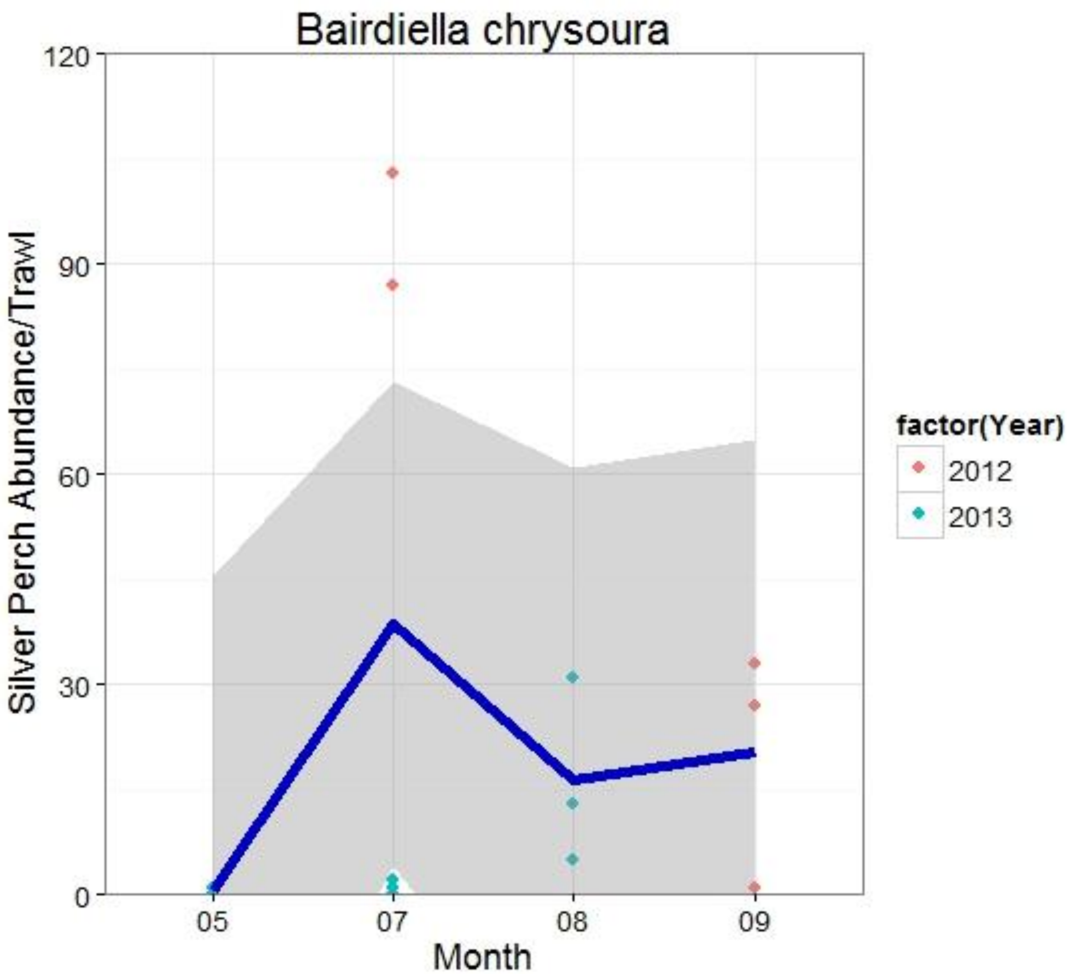
Total Abundance of all Fishes
120
80
40
0
Abundance
05
07
08
09
10
Month
factor(Year)
2012
2013

Figure 7a



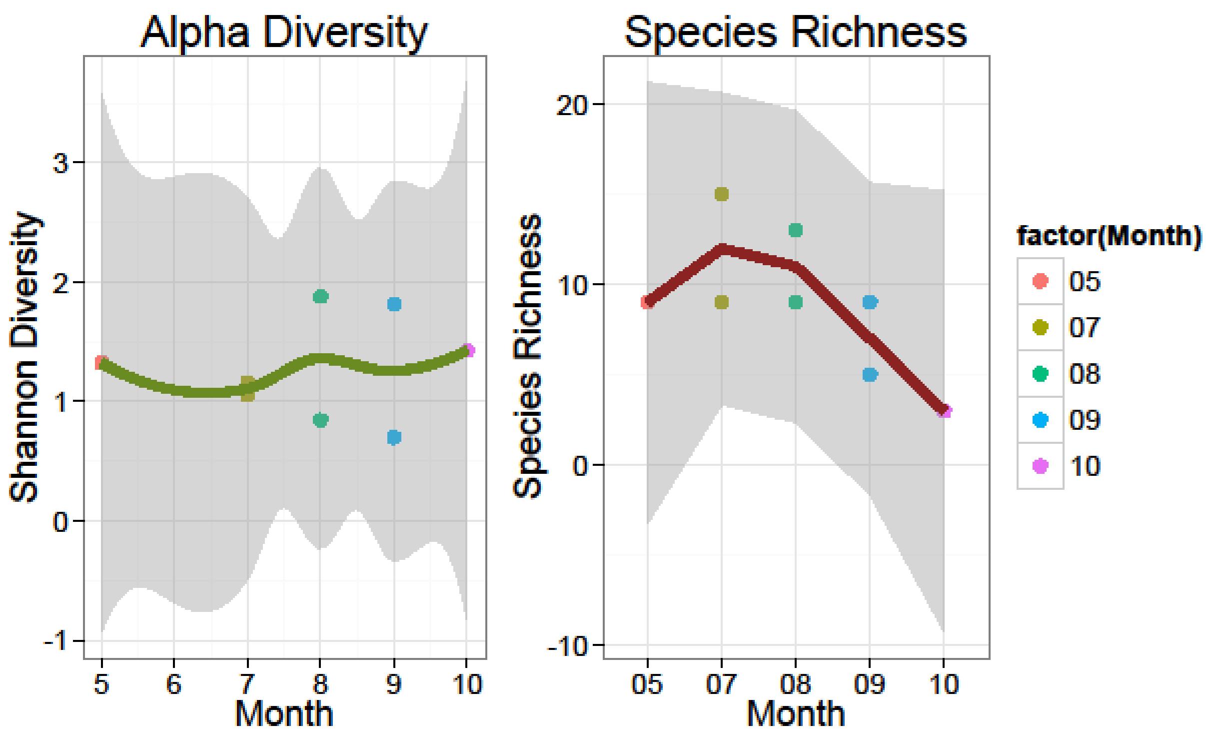
Lagodon rhomboides
Pinfish Abundance/Trawl
120
80
40
0
05
07
08
09
10
Month
factor(Year)
2012
2013

Figure 7b



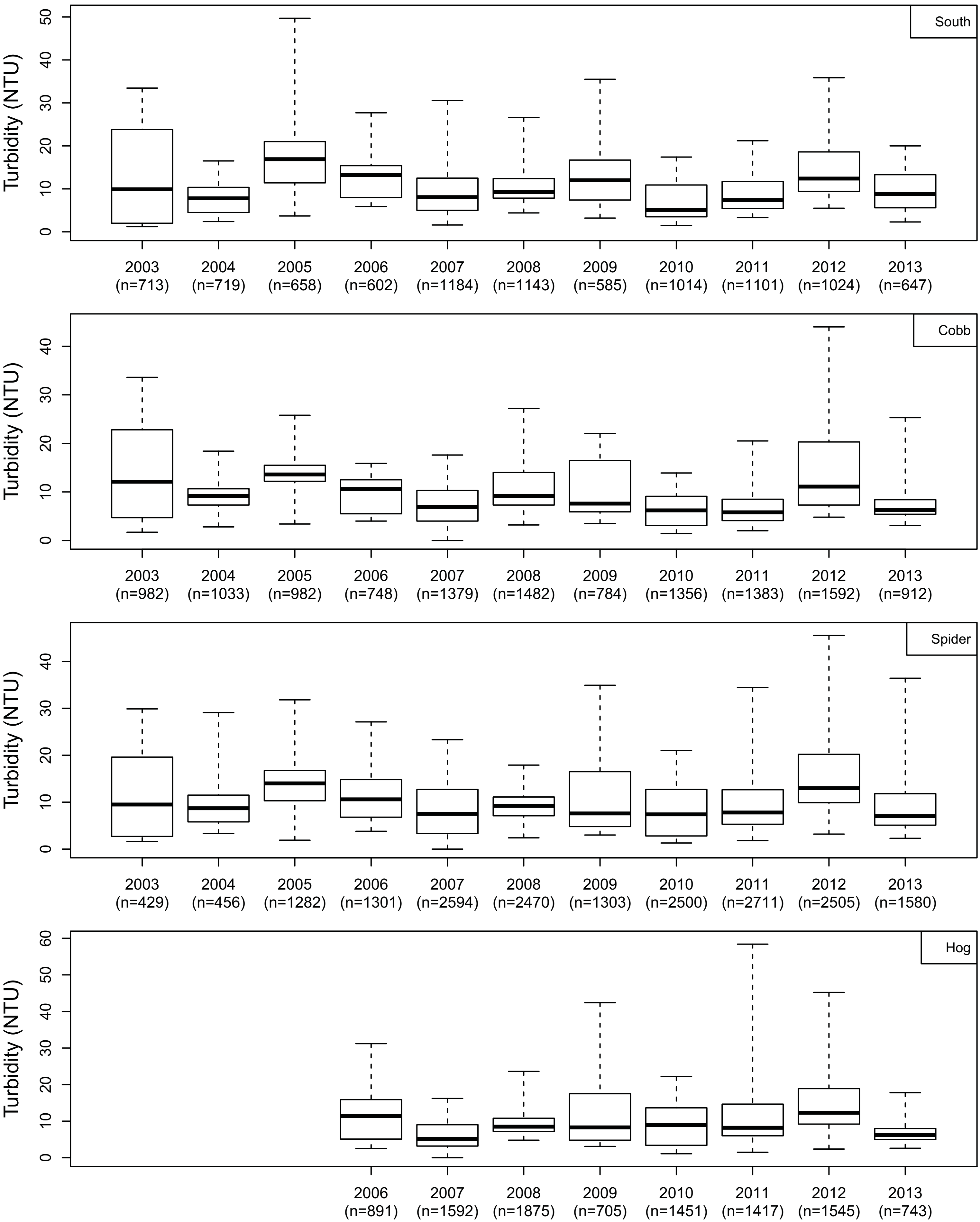
Bairdiella chrysoura
Silver Perch Abundance/Trawl
120
90
60
30
0
05
07
08
09
Month
factor(Year)
2012
2013

Figure 8



Alpha Diversity
Shannon Diversity
3
2
1
0
-1
5
6
7
8
9
10
Month
Species Richness
Species Richness
20
10
0
-10
05
07
08
09
10
Month
factor(Month)
05
07
08
09
10

Figure 9



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)
2013 (n=647)
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)
2013 (n=912)
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)
2013 (n=1580)
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)
2013 (n=743)

Figure 10

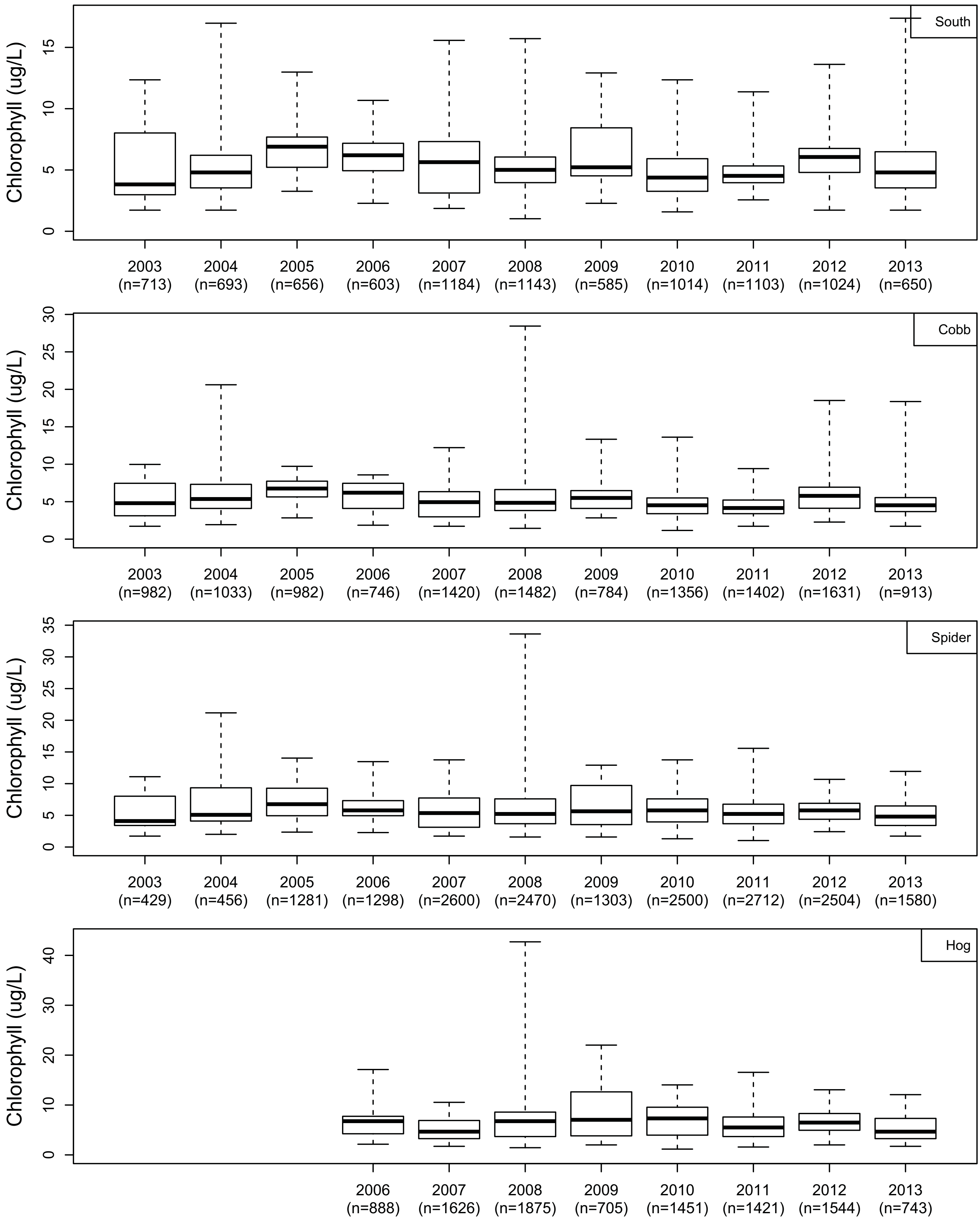

South
Cobb
Spider
Hog
Chlorophyll (ug/L)
0
5
10
15
20
25
30
35
40
2003 (n=713)
2004 (n=693)
2005 (n=656)
2006 (n=603)
2007 (n=1184)
2008 (n=1143)
2009 (n=585)
2010 (n=1014)
2011 (n=1103)
2012 (n=1024)
2013 (n=650)
2003 (n=982)
2004 (n=1033)
2005 (n=982)
2006 (n=746)
2007 (n=1420)
2008 (n=1482)
2009 (n=784)
2010 (n=1356)
2011 (n=1402)
2012 (n=1631)
2013 (n=913)
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)
2013 (n=1580)
2006 (n=888)
2007 (n=1626)
2008 (n=1875)
2009 (n=705)
2010 (n=1451)
2011 (n=1421)
2012 (n=1544)
2013 (n=743)

Figure 11

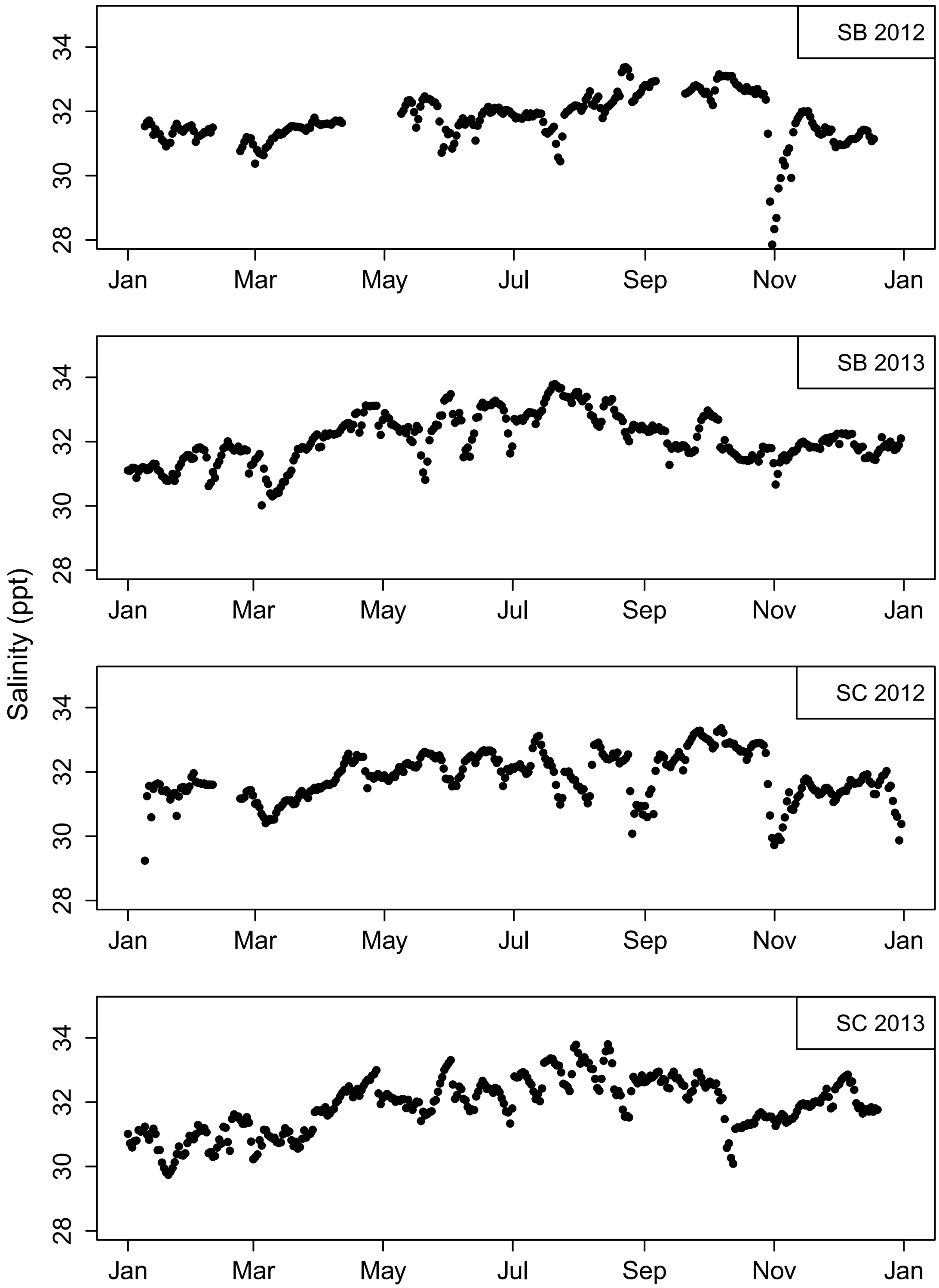

SB 2012
SB 2013
SC 2012
SC 2013
Salinity (ppt)
28
30
32
34
Jan
Mar
May
Jul
Sep
Nov
Jan

Figure 12

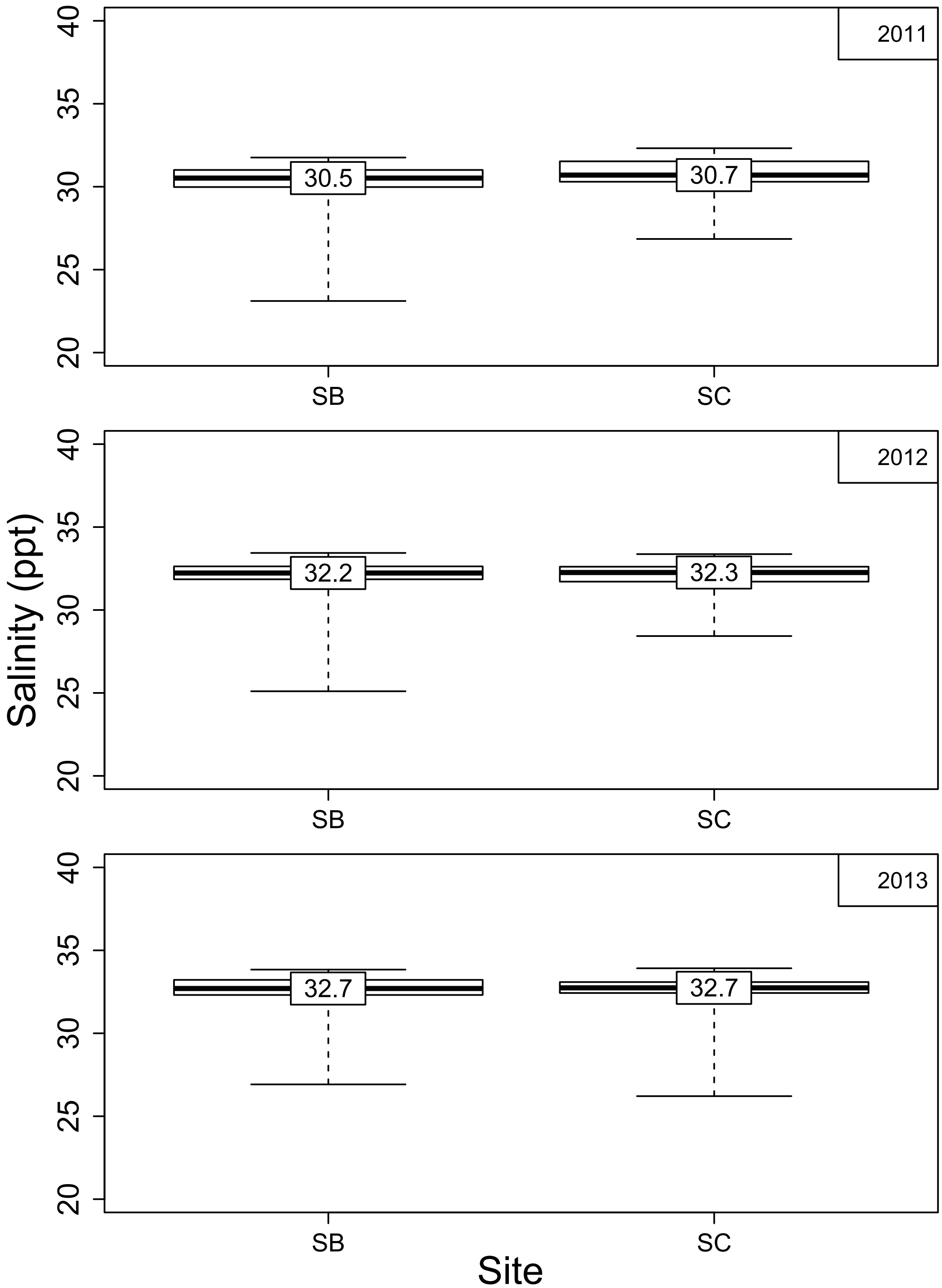

2011
30.5
30.7
2012
32.2
32.3
2013
32.7
32.7
Salinity (ppt)
40
35
30
25
20
SB
SC
Site

Figure 13

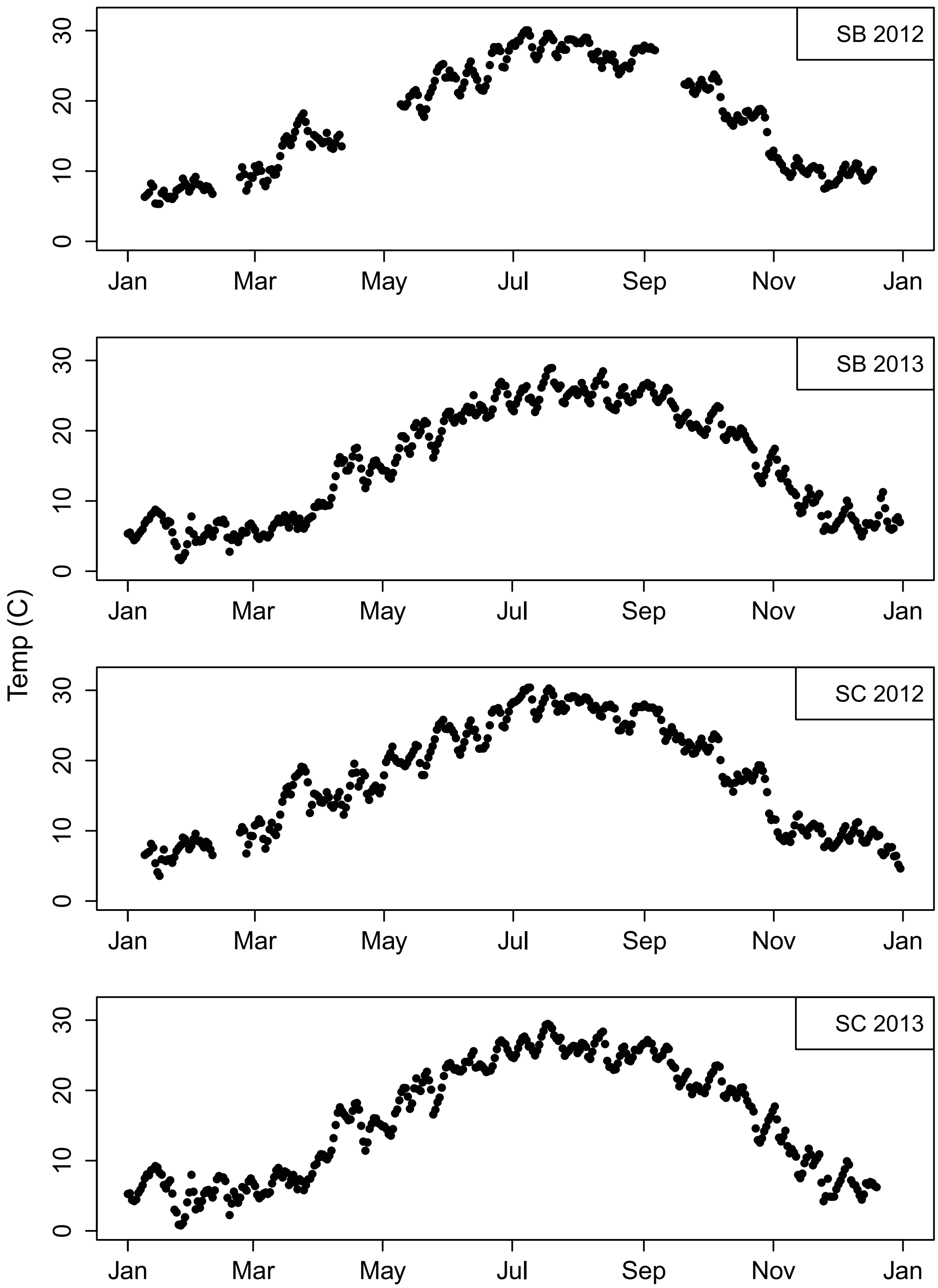
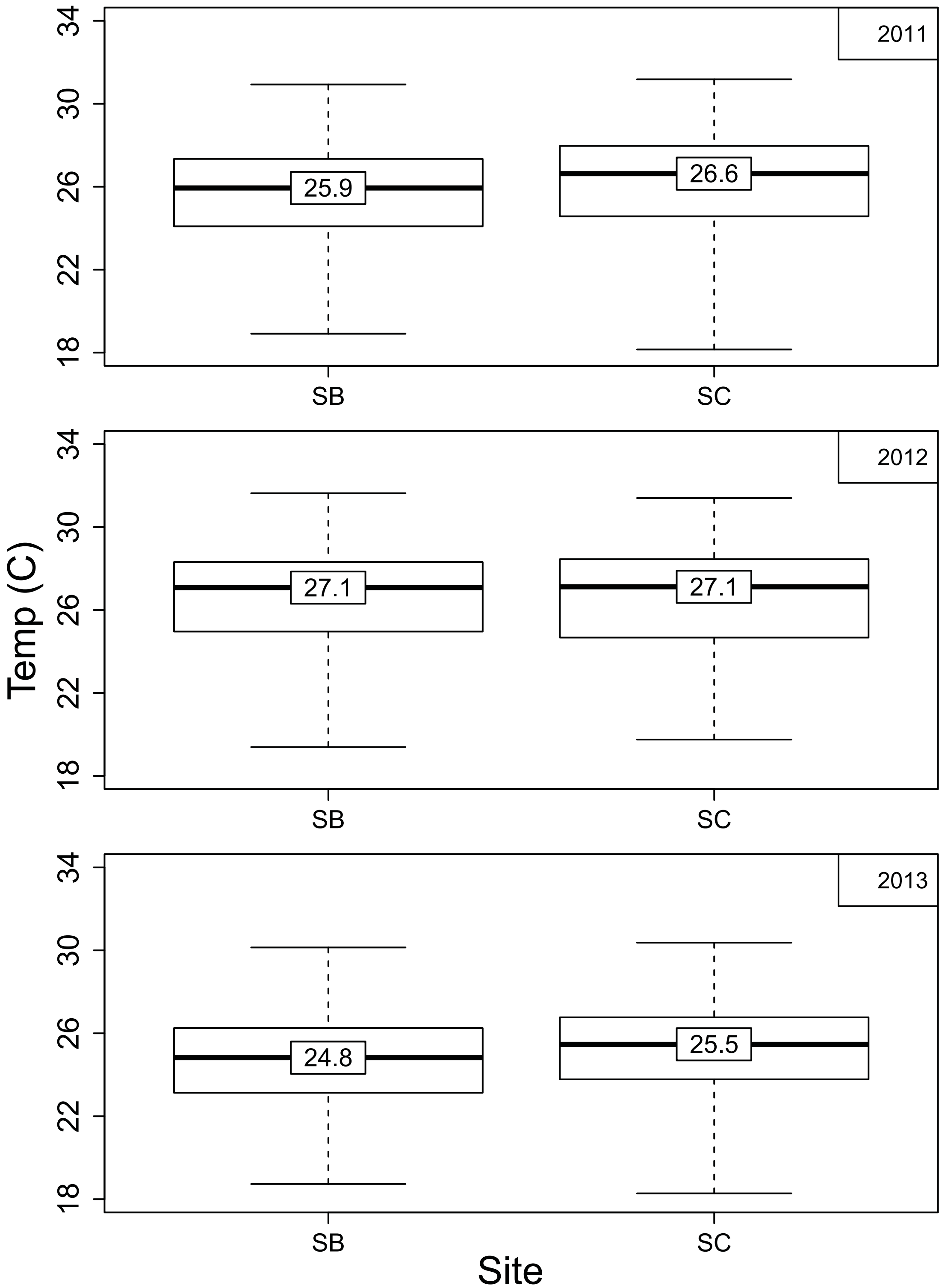

SB 2012
SB 2013
SC 2012
SC 2013
Temp (C)
0
10
20
30
Jan
Mar
May
Jul
Sep
Nov
Jan

Figure 14



2011
25.9
26.6
2012
27.1
27.1
2013
24.8
25.5
34
30
26
22
18
SB
SC
Temp (C)
Site

Figure 15

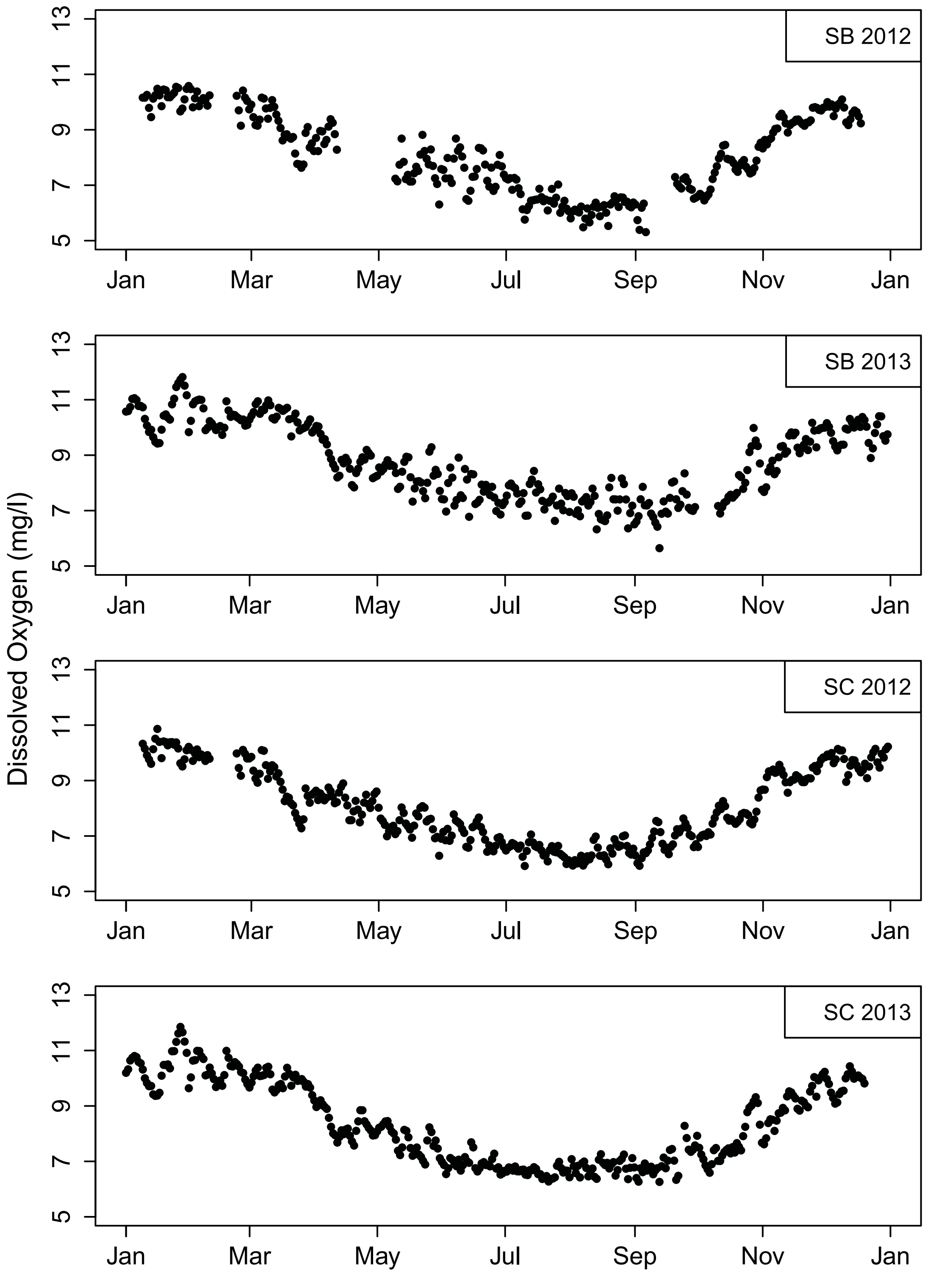
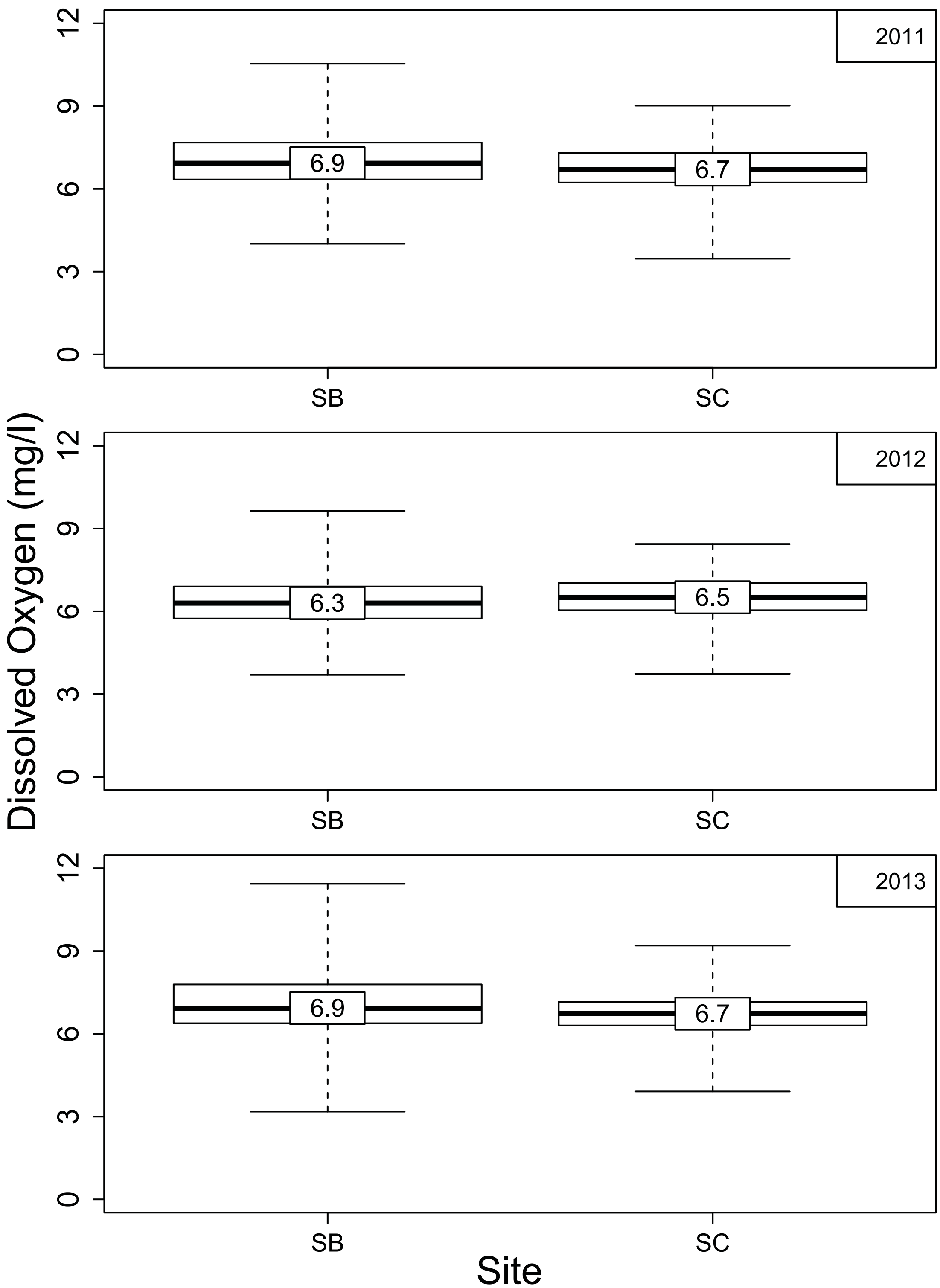

SB 2012
SB 2013
SC 2012
SC 2013
Dissolved Oxygen (mg/l)
13
11
9
7
5
Jan
Mar
May
Jul
Sep
Nov
Jan

Figure 16



Dissolved Oxygen (mg/l)
2011
6.9
6.7
2012
6.3
6.5
2013
6.9
6.7
SB
SC
0
3
6
9
12
Site

Figure 17

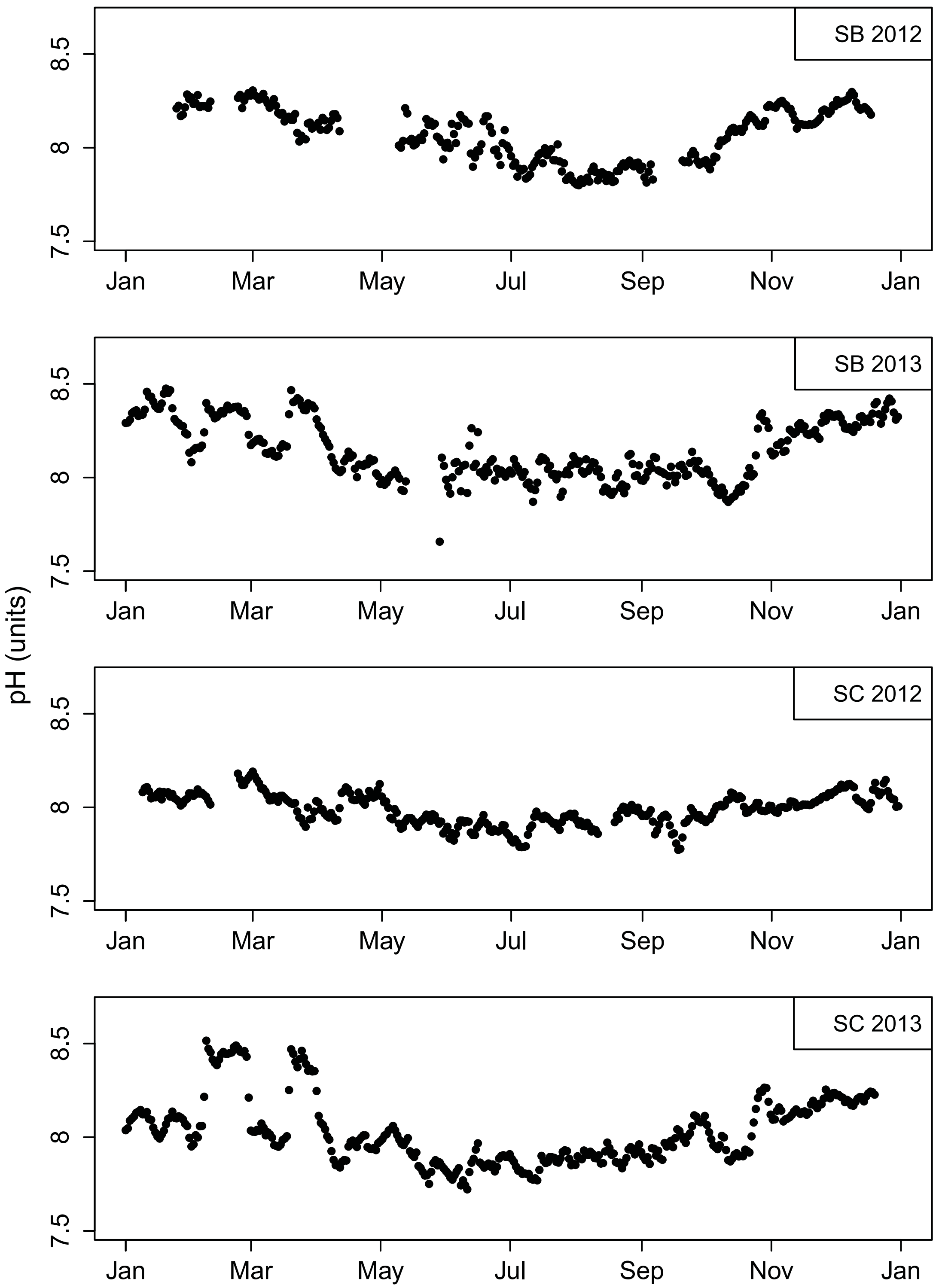

pH (units)
SB 2012
SB 2013
SC 2012
SC 2013
7.5
8
8.5
Jan
Mar
May
Jul
Sep
Nov
Jan

Figure 18

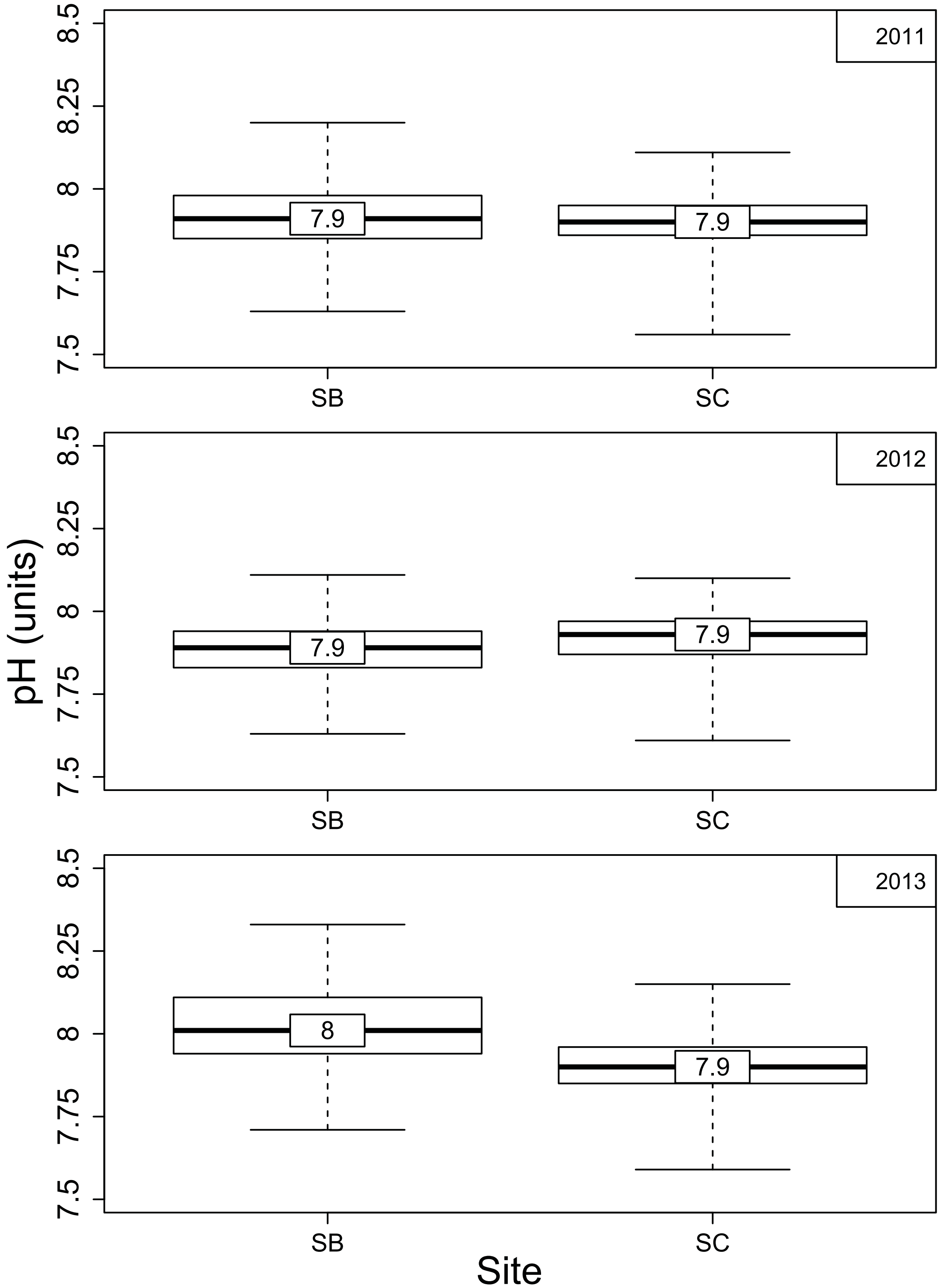

pH (units)
8.5
8.25
8
7.75
7.5
2011
7.9
7.9
SB
SC
2012
7.9
7.9
SB
SC
2013
8
7.9
SB
SC
Site

Figure 19

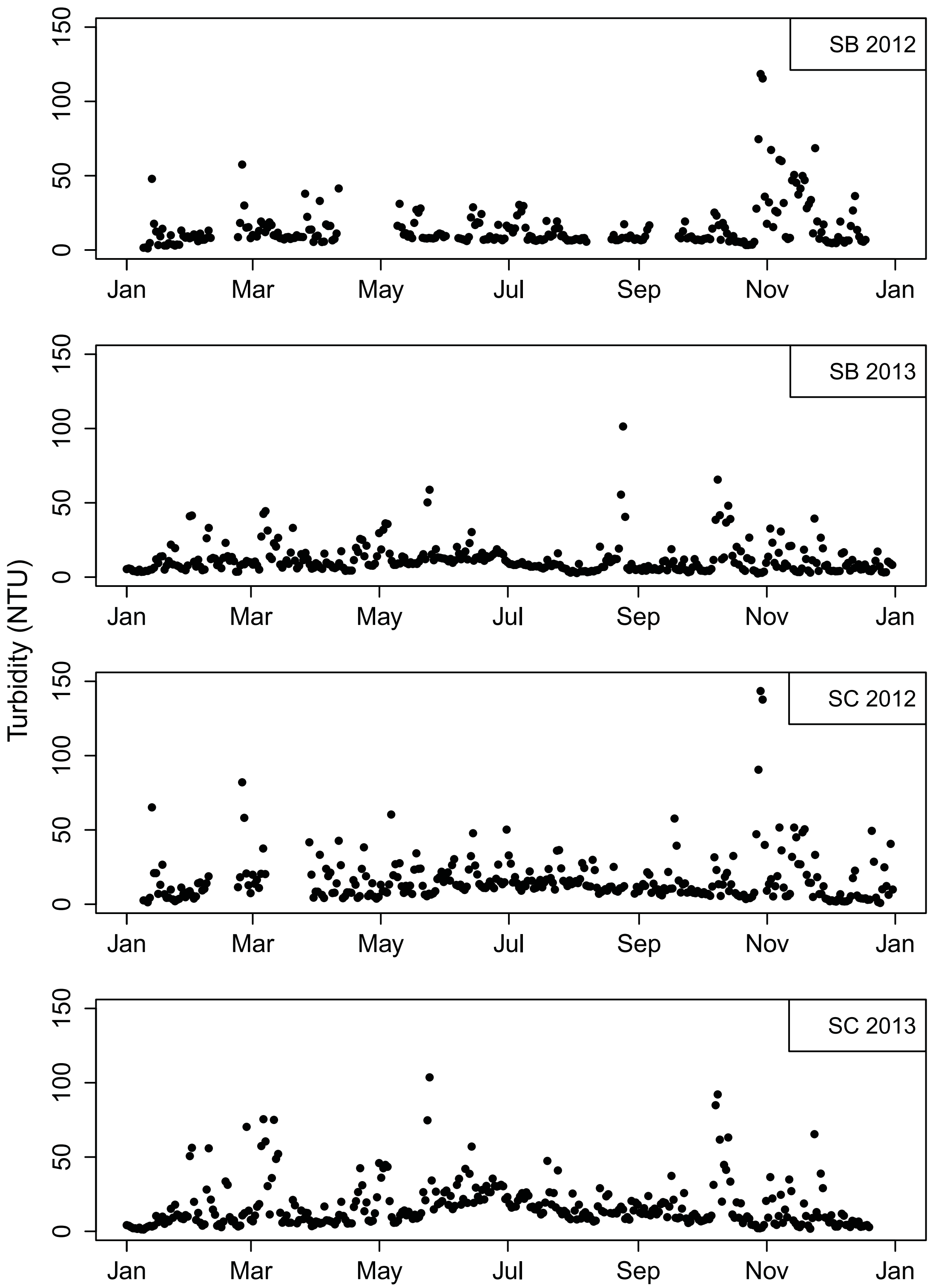

SB 2012
SB 2013
SC 2012
SC 2013
Turbidity (NTU)
0
50
100
150
Jan
Mar
May
Jul
Sep
Nov
Jan

Figure 20

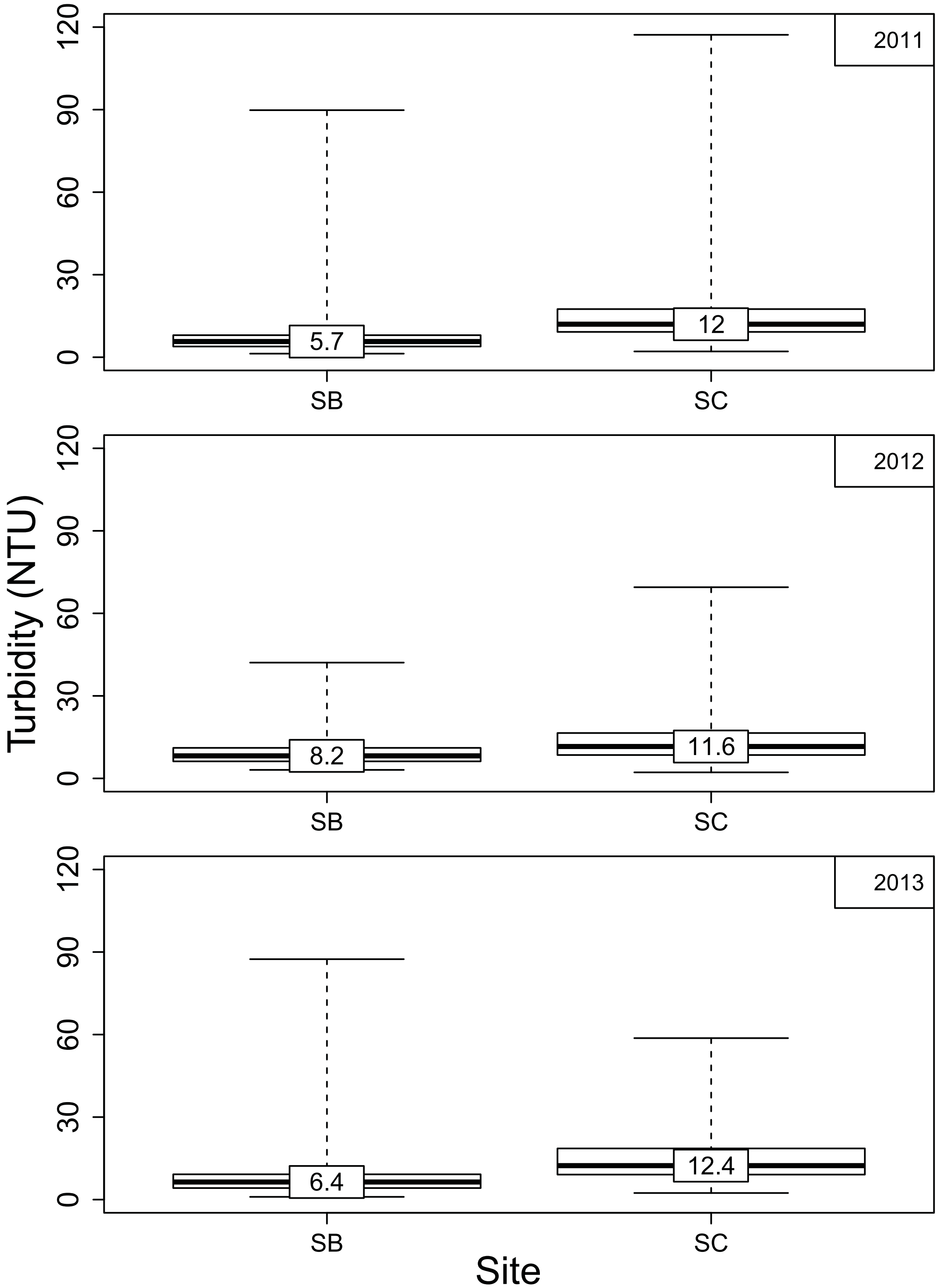

2011
2012
2013
120
90
60
30
0
5.7
12
8.2
11.6
6.4
12.4
SB
SC
Turbidity (NTU)
Site

Figure 21

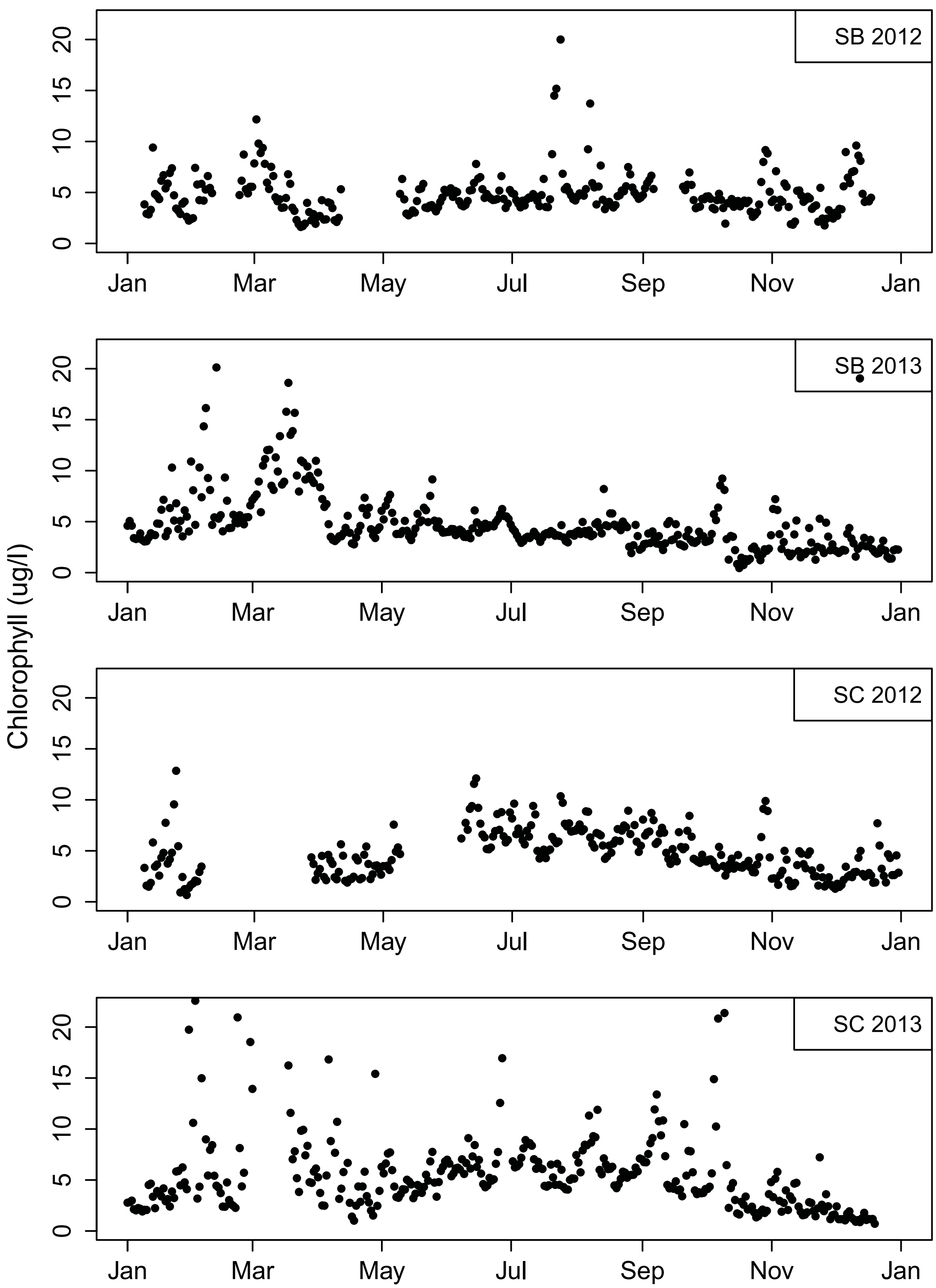
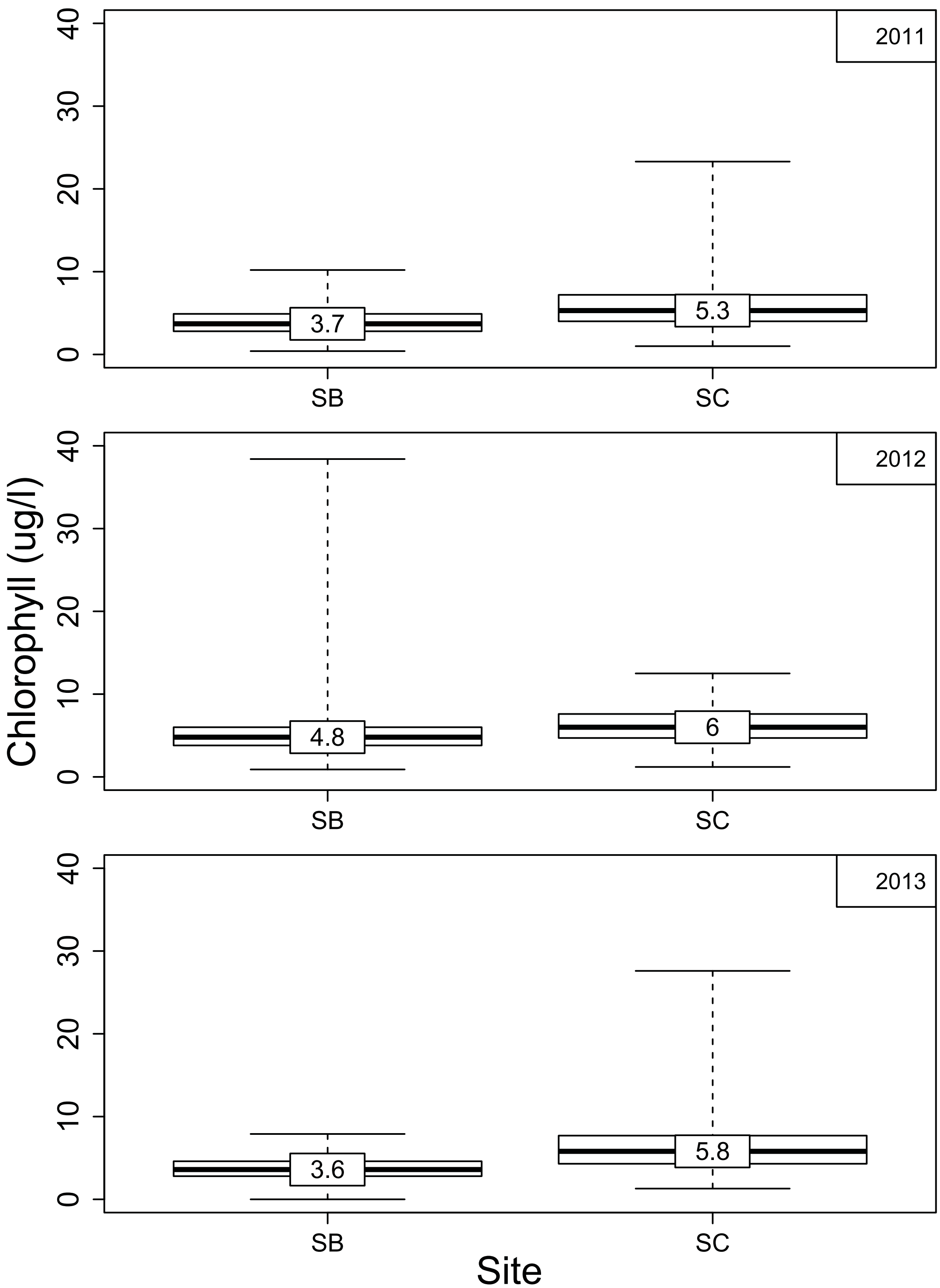

SB 2012
SB 2013
SC 2012
SC 2013
Chlorophyll (ug/l)
0
5
10
15
20
Jan
Mar
May
Jul
Sep
Nov
Jan

Figure 22



2011
3.7
5.3
SB
SC
2012
4.8
6
SB
SC
2013
3.6
5.8
SB
SC
Chlorophyll (ug/l)
Site
0
10
20
30
40