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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# FY2013 Task 11 Eelgrass and Bay Scallop Restoration in the Seaside Bays of Virginia.
(April1, 2014, to September 30, 2015)

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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there followed by a significant hurricane in 1933 that likely eliminated the remaining populations (Orth et al. 2006, unpublished data).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 Virginia 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 through FY2012 Coastal Zone Management 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. South and Spider Crab bays were identified as the bays to receive seeds in 2014. 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, 2014, 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, 2014, eelgrass seeds were hand broadcast from a boat into pre-determined un-vegetated plots in either Spider Crab or South Bay (Figure 2a, b). Plot size during the 2013 project was 0.4 ha (one acre). Seed density was 150,000 seeds per plot.

Germination rates of seeds collected in 2014 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, 2015, 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 to determine seedling success.

**Eelgrass Assessment - Broad Scale**

Atmospheric and water quality conditions over the coastal bays in both spring and fall, 2014, were some of the most difficult we encountered since we began the project. Favorable conditions for flying a mission over these bays (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) did not occur. We made one attempt in Dec. 2014, but the eelgrass had defoliated and was not visible on the imagery.

**Finfish Sampling**

Since 2012 we have conducted monthly nekton (fish) surveys in South Bay 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. These surveys are conducted monthly from May through October.

Once caught, fish size and abundance were recorded and then specimens were released. Unidentifiable specimens were photographed and released, or euthanized with an ice slurry (IACUC-2015-03-16-jprich) and transported to the laboratory for identification confirmation.

Data storage, manipulation and summary statistics were performed with Microsoft Excel. Statistical analyses and plots were performed in R (R Core Development Team 2011).

**Water Quality**

Two complementary approaches to documenting water quality conditions were continued during the FY 2013 reporting period (March 1, 2014- Dec. 2014). Broad spatial patterns in water quality were documented using continuous underway sampling (DATAFLOW) in 2014 as in previous years (this effort commenced in 2003 and has been conducted annually, Orth et al. 2012) (Figure 1). 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 since. Cruises were generally conducted monthly throughout the eelgrass growing season, from March through November of each year. While the length of cruise tracks in vegetated and unvegetated areas varied annually as the eelgrass beds developed and expanded, the track 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 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. Both are equipped with telemetry and real-time data are available through the VECOS web site (www.VECOS.ORG).

Dataflow cruises were successfully completed at monthly intervals from March 2014 through November 2014, excluding the December-February period. Due to a severe winter in early 2015, the YSI stations were lost to ice, compromising the ability to fully analyze the 2014 data set, The YSI's have been re-installed in 2015, so 2014 and 2015 partial data will be reported in the FY2014 report.

All water quality data, both from Dataflow cruises and Continuous data for the 2 YSI's were QA'ed and QC'ed according to EPA and DEQ approved procedures, a long and very challenging task given the massive data sets collected from these two monitoring programs. Final data will be available on the www.VECOS.org web site and in the final report.

**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 are 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, or transferred in fine mesh bags directly to the bottom cages in the grass beds.

**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 openings. 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. To avoid overcrowding, scallops are periodically split into progressively less dense batches in larger meshed bags as they grow. It is also at this time that scallop size is measured and the level of mortality assessed. Finally, during these splits, often times, very fouled cages are replaced with clean ones, ensuring much reduced fouling and reducing maintenance time in the field.

**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 restoration (2012 and 2013) 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 scallops that reside on the bottom substrate.

**Juveniles**

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 predetermined numbers of 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 2014 during a period that range from approximately the midpoint between high and low tides to the midpoint between low and high tides.

**Adults**

Diver surveys to census larger scallops were conducted by randomly selecting 90 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 $m^2$ quadrat and thoroughly search the area within the quadrate, largely by touch as visibility was often poor. Each diver surveyed ten quadrates per transect, yielding a survey of 4500-$m^2$ quadrats in the South Bay grassbed. 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 estimated total scallop numbers in the grassbed.

RESULTS

**Eelgrass Seeding**
In 2014, seeds were broadcast into 51 one acre (0.4-ha) plots in Spider Crab and South bays (Figures 2 a and b) at a seed density of 153,000 seeds per acre for a total of 7,683,000 million seeds (Table 1). Through 2014, 62.05 million seeds have been broadcast into 185.1 ha (457 acres) (Table 1, Figure 3, 4).

**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 2014 was 4.5% (range of 0 – 17.3%). Laboratory germination rates of seeds previously assessed as viable were greater than 77.4% (range of 65.4-89.0%), confirming that the seeds we dispersed were largely viable seeds.

**Meadow Expansion and Development**
In 2014 areal measurements were unavailable for the seaside grassbeds for the reasons described in the methods section of this report.

**Finfish**
Due to a few dominant taxa, total abundance of fishes was highest in the summer months, most notably in July (Figure 5). Pinfish *Logodon rhomboids*, an historically more tropical species, has been very abundant in our samples with its highest abundance in the summer months of July and August (Figure 6). Pinfish size shifts from around 8-cm in July to 12-cm in August and then finally 15-cm in September (Figure 7).

Fish species (β) richness consists of 36 taxa for the sampling years of 2012 – 2014. A full list of these species can be seen in Table 2.

**Water Quality**
Dataflow cruises were successfully completed at monthly intervals from March 2014 through November 2014. . Data show that water quality across the restoration sites continued to be good and supportive of continued SAV growth.Figure 8 a-f presents box plots (median, 25$^{th}$ and 75$^{th}$ percentile and the minimum and maximum of the lower 99% of the data) for each of the restoration areas during the March-November 2014 SAV growing season. Median temperatures (Figure 8f) were nearly identical at 20$^{o}$C among all the sites. Median salinities (Figure 8b) again were very similar (31.4 to 31.6) at all sites, however, salinities occasionally reached lower levels at South and Spider Crab bays. Similarly dissolved oxygen and pH levels (Figures 8c and 8d) were very similar across the bays in 2014 although the slightly lower pH observed at Cobb,

South and Spider Crab sites were not observed at Hog Island Bay. Turbidity medians ranged between 8.5 NTU at Hog Island to 9.6 at South Bay (Figure 8a). Although turbidity levels were slightly lower at Hog Island, the upper 99% of concentrations reached nearly 10 NTU higher than the other sites suggesting that higher short term pulses of high turbidity were observed there. Chlorophyll concentrations were lowest at 5.1 µg/l at South and Cobb Bays, increasing to 5.6 at Spider Crab and 6.1 at Hog (Figure 8e).

Figure 9 a – d, presents a time series of the yearly March through November integrated, median 25% and 75% quadrille, maximum and minimum of the chlorophyll levels recorded by the DATAFLOW cruises across each of the four restoration areas for the entire 2003-2014 restoration project period. Overall the pattern of lower median levels of CHLa found in 2014 in Cobb and South Bays were generally consistent over the entire time period. Annual variability was distinctly evident with markedly higher concentrations in 2005 and 2006 as well as 2012 at all the sites. Hog Island Bay (Figure 9 d) consistently had the highest levels with an overall median of 6.5 µg/l compared to 5.2 and 5.0 at Cobb and South respectively (Figures 9 b and a).

Figure 10, presents a time series of the yearly March through November 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 2003-2014 restoration project period. Turbidities measurements are reflective of suspended particle concentrations. These particles are usually comprised of inorganic and non-living organic particles as well as phytoplankton. All four restoration areas showed similar patterns in median annual turbidity throughout the project period. Elevated turbidities were especially evident in 2012 when median levels exceeded 12 NTU. 2005 had the highest median turbidity levels ranging from 14 to 17 NTU. This was approximately double the median levels observed between 2003 and 2014, which ranged from 8 to 9.5 NTU. 2014 levels were near the long term medians at each site indicating a very average year. Overall Cobb Island Bay (Figure 10 b) typically has had the lowest long term turbidity at 7.8 NTU with South Bay the highest at 9.3 (Figure 10 a). For this region we have calculated that the seasonal light requirements for seagrass growth in this region are approximately 10 NTU or lower. Therefore all the sites usually have suitable turbidities long term for plant growth to the seagrass restoration depths being used here (Figures 10 a – d).

**Scallop Seed Production**

The results of this work are evident in the next section. Spawning stocks from the nursery are transported to the cage arrays that are maintained in the South Bay grassbeds (See below).

**Maintenance of Scallop Spawning Stocks in Grass beds**

During the beginning of the study period, VIMS staff maintained 50,000 scallops produced in 2013 in the cages of South Bay. These animals spawned during the spring and again in September in the grassbed. Through the summer over 700,000 scallops produced during the spring of 2014 grew to exceed our cage capacity. On August 28, 2014, 200,000 off the largest of these animals were split into 40 bags and the remaining 500,000 were released directly into the grassbed. These now "wild" scallops should have spawned in the spring of 2015.

By October, 2014, VIMS had approximately 309,000 scallops within the South Bay grassbed cage array. A cohort spawned in the fall of 2013 had over 49,000 adult scallops in the cages.

These were released into the grassbeds on October 6, 2014. Bay scallops from the spring 2014 spawns held in the grassbed cages totaled 195,000. By spring 2015 these animals had grown too large for the cages. In April 2015 they were thinned to a total of 120,000 in cages and the remaining animals were released into the grassbeds. Sixty-five thousand small juveniles from the fall 2014 spawns were placed into cages in the grassbed in early October 2014. By the end of the winter 31,000 of these had survived which, given their small size and the severity of winter, was a success.

VIMS maintained approximately 265,000 scallops produced from spawns in 2014 in cages in the South Bay grassbed going into the preceding winter. Following an exceptionally cold winter with extensive sea ice at the site, an assessment in April 2015 confirmed that the scallops had suffered approximately 62% mortality, leaving 100,600 surviving scallops. In April 2015, 58,000 of these scallops were released directly into the grassbed in South Bay and the remaining held in cages until the end of the summer at which time 14,900 were released into South Bay and approximately 27,200 were released into the grass bed in Cobb Bay.

**Assessment of Wild Scallop Population**

During July 2014 an extensive survey of 1275 acres within the South Bay grassbed was conducted using divers and suction sampling. This survey yielded an estimate of 521,000 juvenile scallops and 113,000 free-living adult scallops within the South Bay grassbed (Figure 11a). Therefore we estimate a mean of 0.022 adult scallops per square meter of grassbed in South Bay (Figure 11b). Data for the juvenile scallops sampled by suction sampling are not shown.

DISCUSSION

**Eelgrass Bed Development**

The use of seeds in the recovery of eelgrass in the Virginia coastal bays continued successfully in 2014. 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. We were able to broadcast seeds into more acres (51) albeit at a lower seed density than in 2013 because of the high quality of the seeds we noted during the curing process in our greenhouse. This observation was supported by our higher establishment rates in the spring of 2015 with rates as high as 17%. While we were unable to acquire necessary imagery to map the grassbeds in 2014, our observations during our general surveys of the region suggested that grassbeds were vibrant, and present in all locations noted in the 2013 beds in South Bay which had been mapped in 2013. Our general assessment that had we had imagery for 2014, we undoubtedly would have had more eelgrass than what was fully mapped in all four bays in 2012.

**Finfish**

The high abundance of fishes in the summer (Figure 5) is most likely a function of seasonal temperature that determines the timing of their visit to the South Bay grassbeds. These data help us to better understand the food web dynamics of the grassbeds, and, more practically, they assist in more informed decisions regarding the timing of scallop releases. Using these data we hope to conduct “smart releases” of scallops, timed to avoid maximum predation by all predators and in particular, pinfish which have been seen in higher abundance in South Bay in recent years (Figure 6), especially during the summer months.

In addition to their high summertime abundance, the ontological shift in the diets of pinfish make them of special concern for juvenile scallops in the field (Figure 7). Pinfish undergo a dietary shift as they grow in that they prefer small crustaceans until they reach a size of 60mm and then from 61 – 120 mm then feed on larger benthic invertebrates including bivalve mollusks. Around 120 mm pinfish become herbivorous (Livingston, 2003).

This size shift can be seen in Figure 7. From these data, it is apparent that in general, the summer months are probably more dangerous for juvenile scallops due to high fish abundance and pinfish food preference when pinfish are present. This is also in line with recent work by (Schmitt et al. in press) where they found large numbers of pinfish in the predaceous size range, in July, with 2013 having a very high mean abundance compared to 2014. With this growing body of knowledge and continued predator sampling we hope to utilize these data to time the release of juvenile scallops to avoid high predation by pinfish and other predators, including blue crabs, in the future.

**Water Quality in the Virginia Coastal Bays**

Water quality monitoring of the four restoration areas in 2014 indicates that, overall, water quality remained high for eelgrass growth and restoration in all of the coastal lagoon areas studied. Growing season, salinity pH, dissolved oxygen, and temperature were very comparable across all the sites and generally within the ranges necessary for growth and spreading of eelgrass. By themselves they should not be limiting seagrass growth. Both turbidity and phytoplankton concentrations in 2014 showed higher ranges at Hog island Bay where restoration success has been less. This may be due in part to local resuspension of sediment and benthic microalgae, both of which may be related the lack of seagrass bed cover. Local resuspension can inhibit bed development and seedling survival up to a point where seagrass sediment stabilization begins to greatly reduce this. It may also be that fine suspended sediments are being transported in from other or deeper areas as a function of the physical circulation or tidal patterns in this bay. More detailed monitoring at this site may provide evidence as to the patterns here and how they compare to the other restoration areas.

**Scallop Restoration**

Previous reports (FY11 Task 12 and FY12 Task 11) have detailed our restoration strategy for bay scallops and the early success that we have had in (a) developing and maintaining a Virginia brood stock line of bay scallops, (b) spawning, maintaining and out planting scallops in the grass bed, and (c) establishing a wild population in the grass bed. Recent anecdotal evidence of bay scallops from elsewhere in the Virginia seaside coastal bays, clearly demonstrate that bay scallops have spread beyond the areas in which we have stocked. Our quantitative survey of juveniles and adults in 2014, which showed a substantial increase in large scallops (Figures 11a, 11b), continues our proof of concept that enhancement of the bay scallop population can be achieved. However, though we are very encouraged by the successes to date, in our best informed judgment the standing stock of wild bay scallops has not reached a point at which we expect that it will be self-sustaining (Figure 11b). We will need to achieve an order of magnitude higher population level for a self-sustaining population. Thus, as we move forward in this project we will be constantly seeking ways to improve our restoration strategy and its success.

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**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 $10^6$ | Area (ha) | Plot size (ha) | n plots | Seeds x $10^6$ | 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 | | | | | | | | |
| 2014 | 4.05 | 10.8 | 0.4 | 27 | | | | |
| Total | 11.55 | 35.1 | | 95 | 5.1 | 15.0 | | 49 |

| | Spider Crab Bay | | | | Hog Island Bay | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Seeds x $10^6$ | Area (ha) | Plot size (ha) | n plots | Seeds x $10^6$ | 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 | | | | |
| 2014 | 3.6 | 9.6 | 0.4 | 24 | | | | |
| Total | 41.6 | 116.9 | | 316 | 3.8 | 18.2 | | 58 |

**Table 2.** Species list of fauna collected during the trawl period from 2012 – 2014.

| Common Name | Species | Total |
|---|---|---|
| Silver Perch | *Bairdiella chrysoura* | 3520 |
| Pinfish | *Lagodon rhomboides* | 772 |
| Atlantic Silverside | *Menidia menidia* | 482 |
| Northern Pipefish | *Syngnathus fuscus* | 392 |
| Blue crab | *Callinectes sapidus* | 368 |
| Pigfish | *Orthopristis chrysoptera* | 246 |
| Spot | *Leiostomus xanthurus* | 179 |
| Sheepshead | *Archosargus probatocephalus* | 128 |
| Dusky Pipefish | *Syngnathus floridae* | 48 |
| Black Seabass | *Centropristis striata* | 33 |
| Gag Grouper | *Mycteroperca microlepis* | 31 |
| Toadfish | *Opsanus tau* | 19 |
| Spot | *Leiostomus xanthurus* | 16 |
| Striped Burrfish | *Chilomycterus schoepfii* | 9 |
| Tautog | *Tautoga onitis* | 9 |
| Summer Flounder | *Paralichthys dentatus* | 8 |
| Silver Jennie | *Eucinostomus gula* | 6 |
| Spotted seatrout | *Cynoscion nebulosus* | 6 |
| Puffer | *Sphoeroides maculatus* | 4 |
| Conger eel | *Conger oceanicus* | 4 |
| Northern Sennet | *Sphyraena borealis* | 3 |
| Red drum | *Sciaenops ocellata* | 2 |
| Southern Stingray | *Dasyatis americana* | 2 |
| Anchovy | *Anchoa mitchelli* | 2 |
| Spottail pinfish | *Diplodus holbrookii* | 2 |
| Sea Robin | *Prionotus* | 2 |
| Spotfin Butterfly Fish | *Chaetodon ocellatus* | 2 |
| Striped blenny | *Chasmoides bosquianus* | 1 |
| Planehead filefish | *Stephanolepis hispida* | 1 |
| Spotted codling | *Urophycis regia* | 1 |
| Grouper | *Myctoperca* | 1 |
| Carax sp. | *Carax sp* | 1 |
| Northern Kingfish | *Menticirrhus saxatilis* | 1 |
| Inshore Lizardfish | *Synodus foetens* | 1 |
| Eucinostomus sp. | *Eucinostomus sp.* | 1 |
| Blue Spotted Cornetfish | *Fistularia tabacaria* | 1 |

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. Maps showing (a) the 23 0.4-ha plots of Spider Crab Bay and (b) the 28 0.4-ha plots of South Bay each of which received 150,000 eelgrass seeds in 2014.

Figure 3. Cumulative area of seeding and total area estimate from the aerial mapping for all four seaside bays through 2014 (Note – area data for the 4 bays were unavailable for 2013 and 2014 – 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. Total fish abundance/150-m trawl for the months of May (05) through October (10) for the years of 2012 through 2014. Shaded area shows the 95% CI about the mean (red line).

Figure 6. Time series of the mean abundance of pinfish per 150-m trawl over the course of the survey period from 2012 through September 2014. The error bars indicate the standard error about the mean.

Figure 7. Bar plot showing the number of pinfish as a function of fish length, with colors representing the factor month with red = July, green = August, and blue = September.

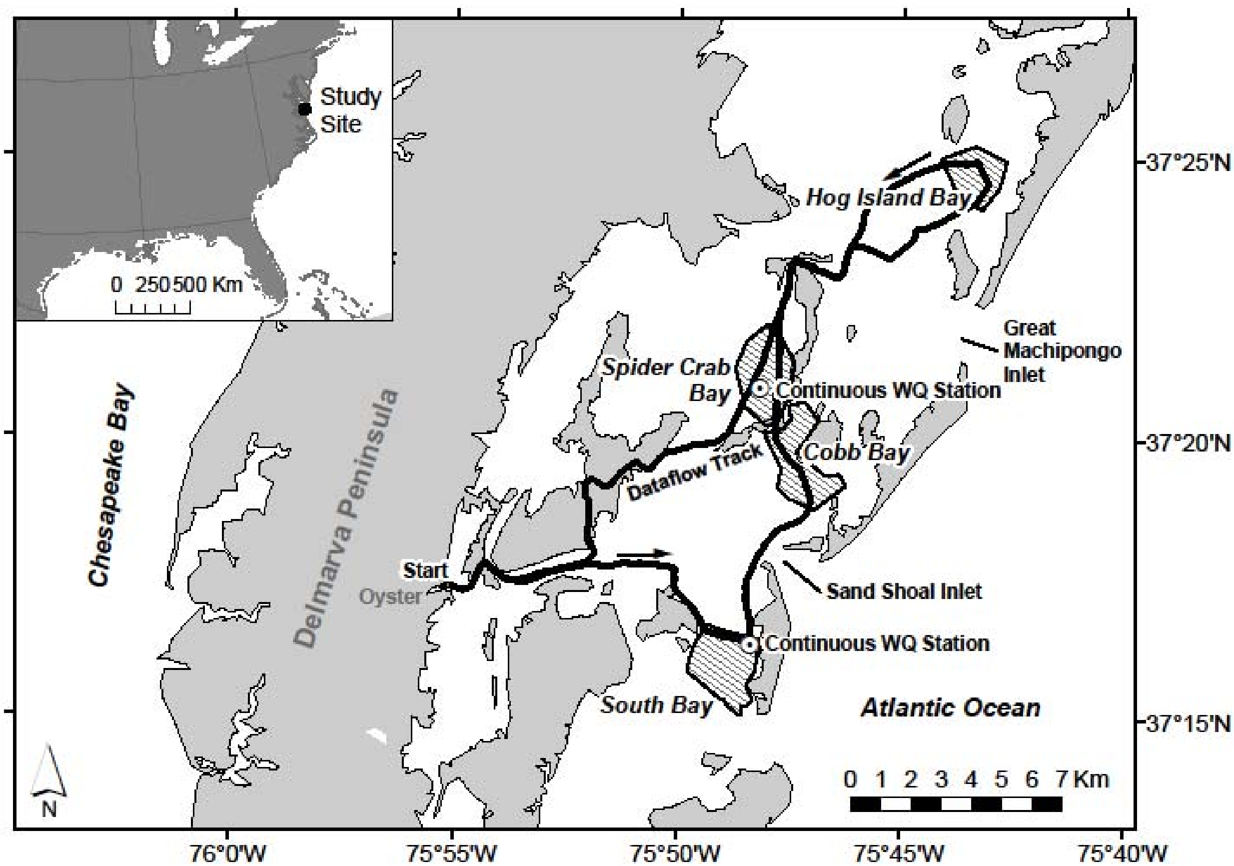
Figure 8. Box plots showing DATAFLOW (a) turbidity concentrations (median, 25th and 75th percentiles, and the minimum and maximum of the lower 99% of the data) from four restoration bay areas for the March-November periods from 2013-2014, and the same for (b) salinity (psu), (c) dissolved oxygen (mg/L), (d) pH, (e) Chlorophyll-a, and (f) Temperature ($^{o}$C)

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 2003-2014.

Figure 10. 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 2003-2014.

Figure 11. Bar plots showing the (a) population estimate of adult scallops as estimated by extrapolating our surveys to the area of the South Bay grassbed, and (b) the estimated number of scallops per square meter in the same grassbed.

**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

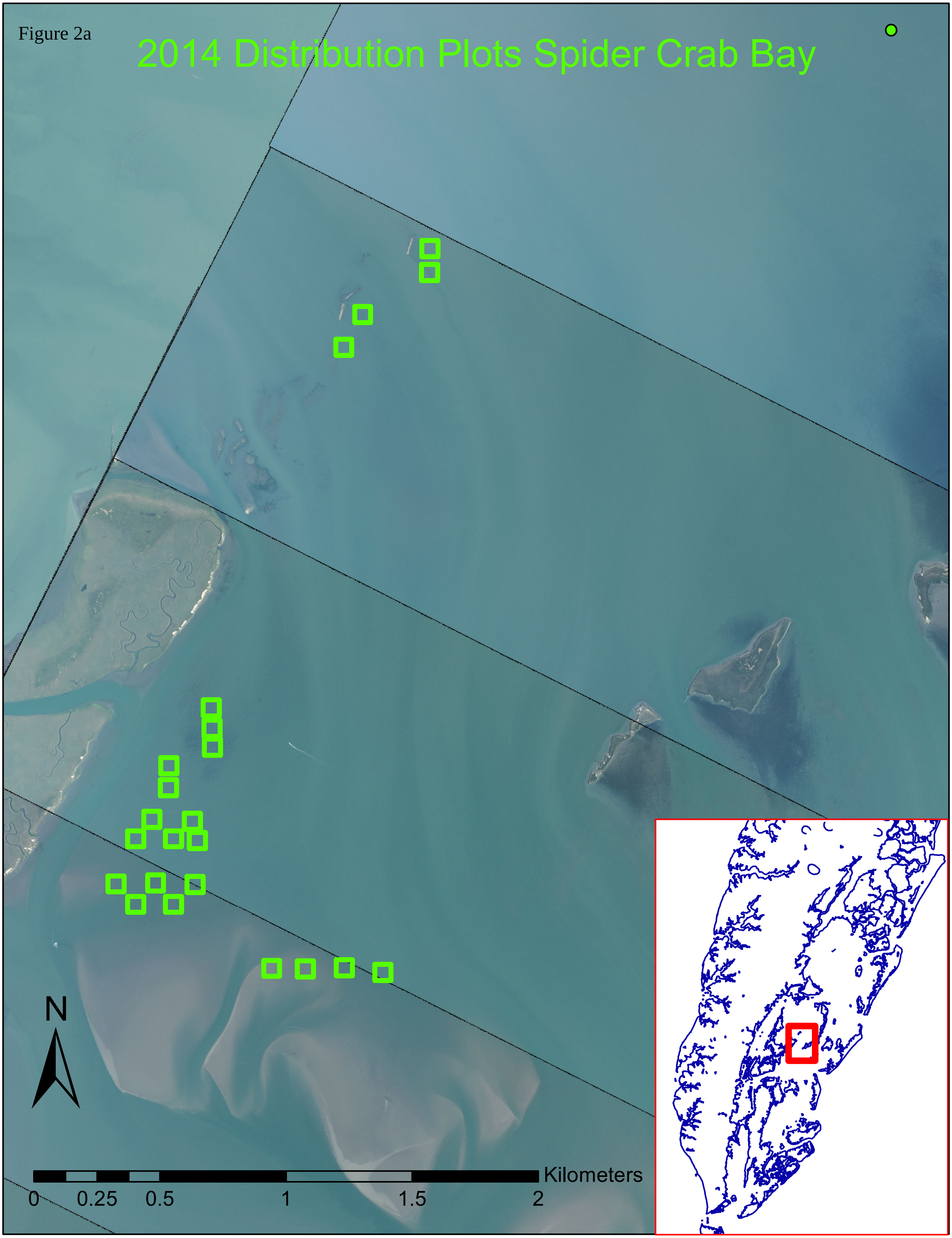


Figure 2a
2014 Distribution Plots Spider Crab Bay
N
Kilometers
0
0.25
0.5
1
1.5
2

Figure 2b

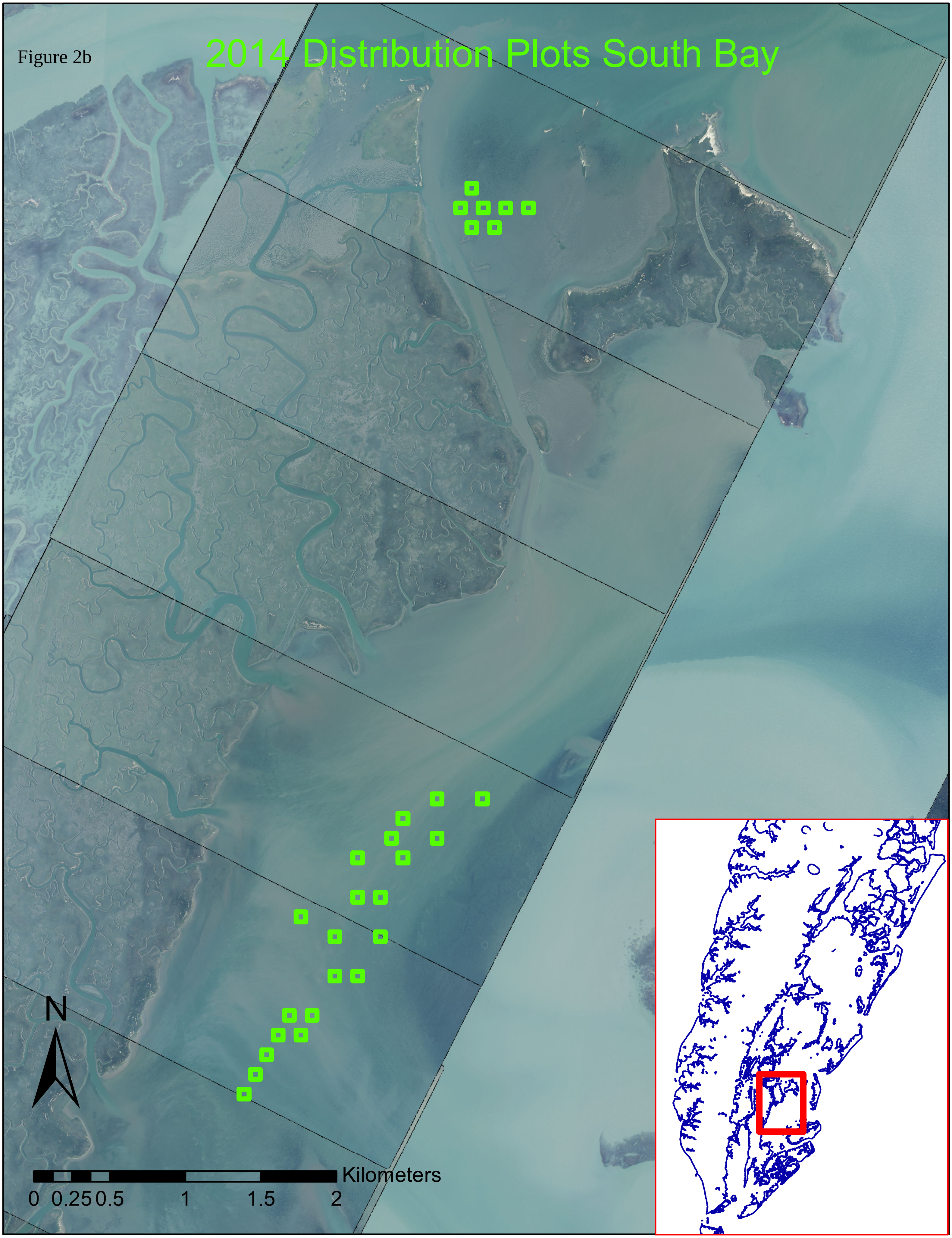
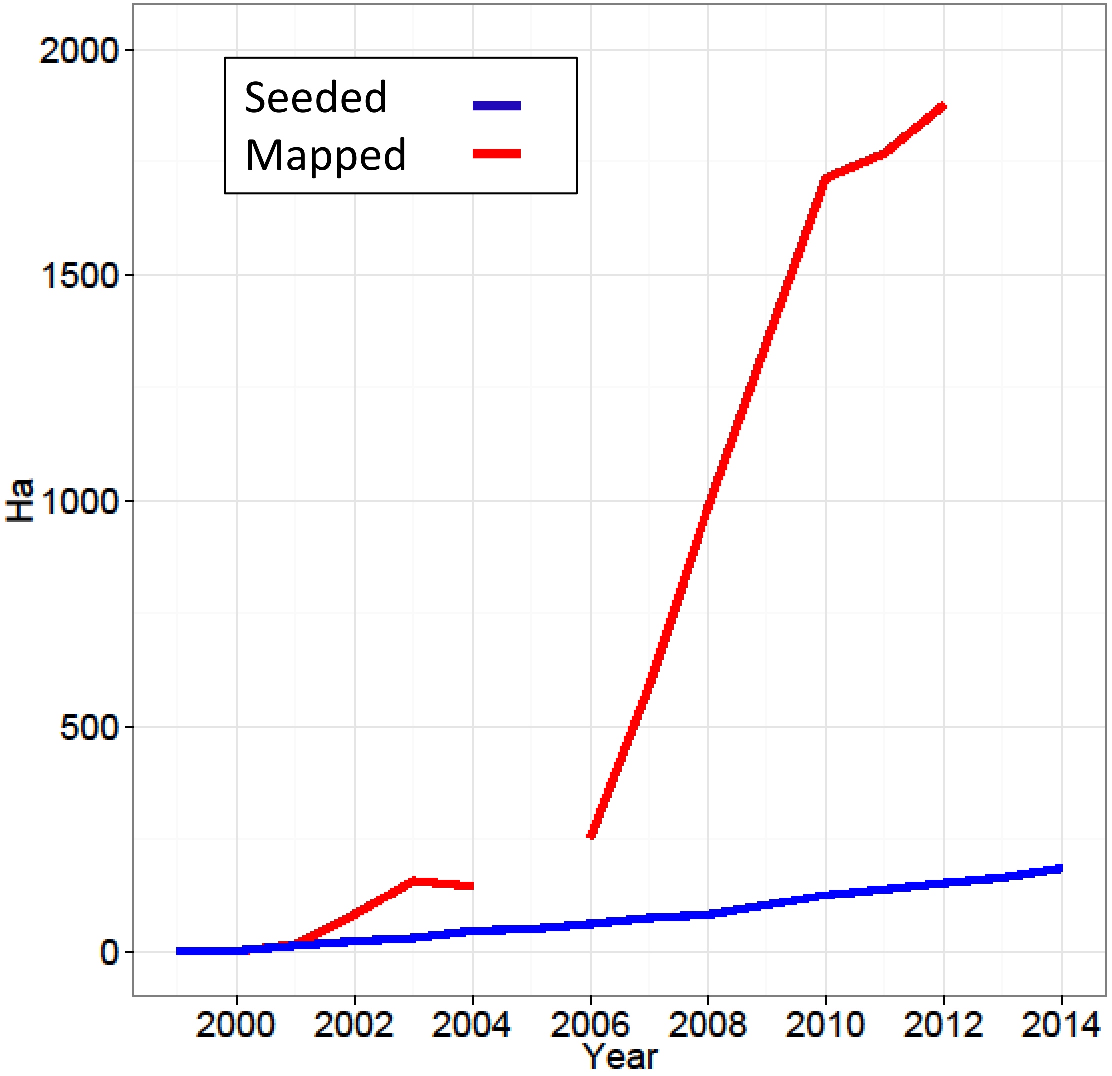
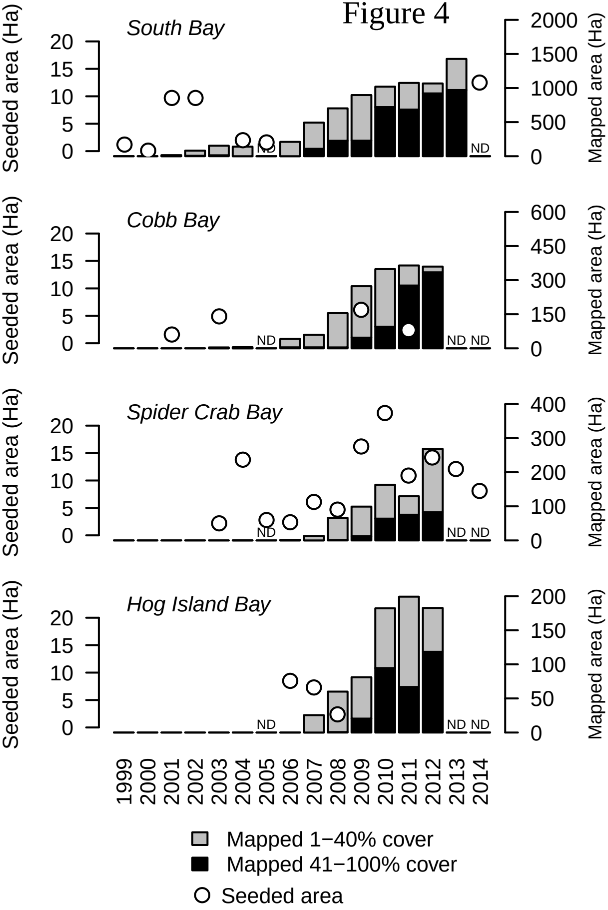

2014 Distribution Plots South Bay
N
0 0.25 0.5 1 1.5 2
Kilometers

Figure 3



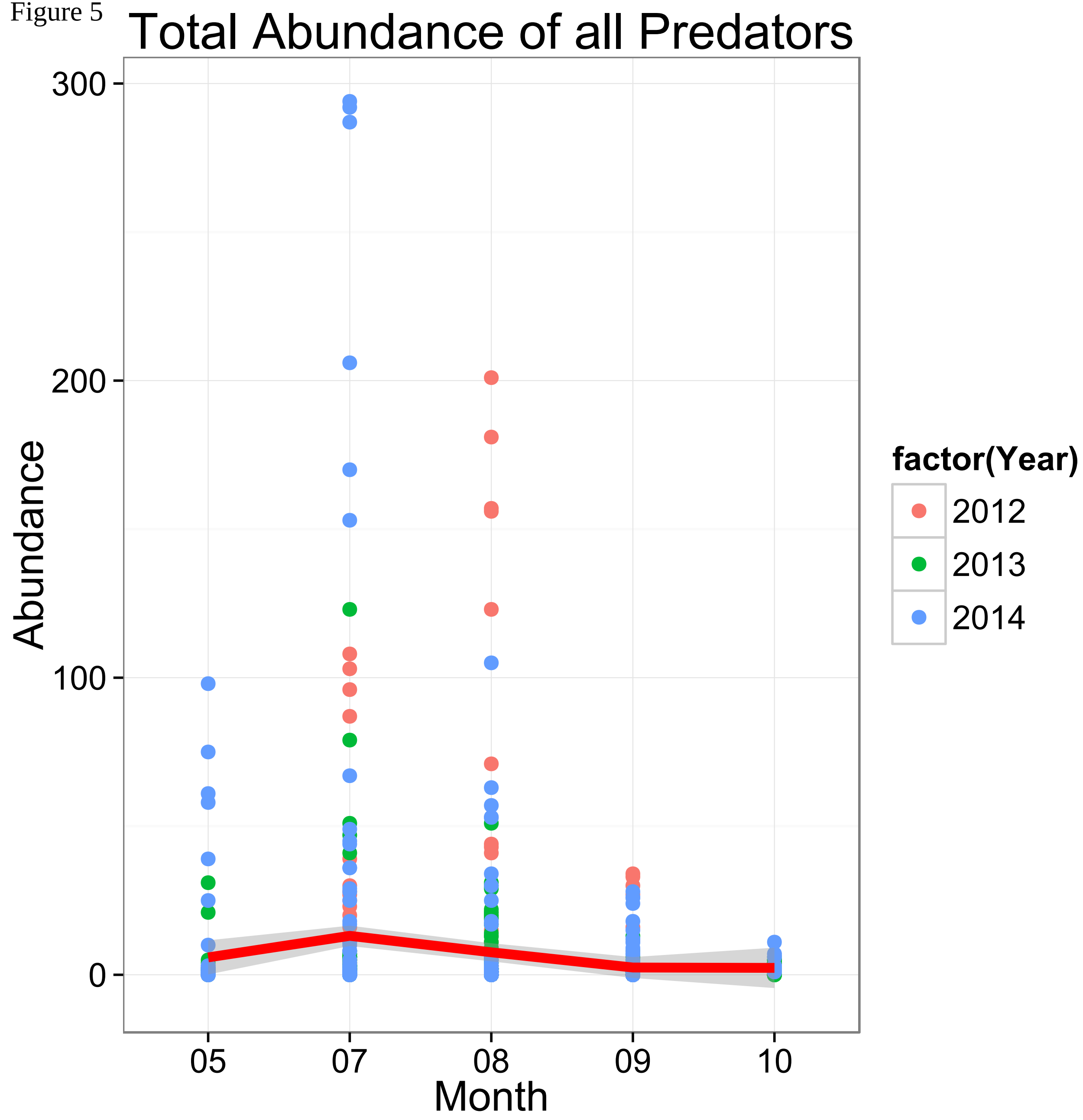
Seeded
Mapped
2000
1500
1000
500
0
Ha
2000
2002
2004
2006
2008
2010
2012
2014
Year

# Figure 4



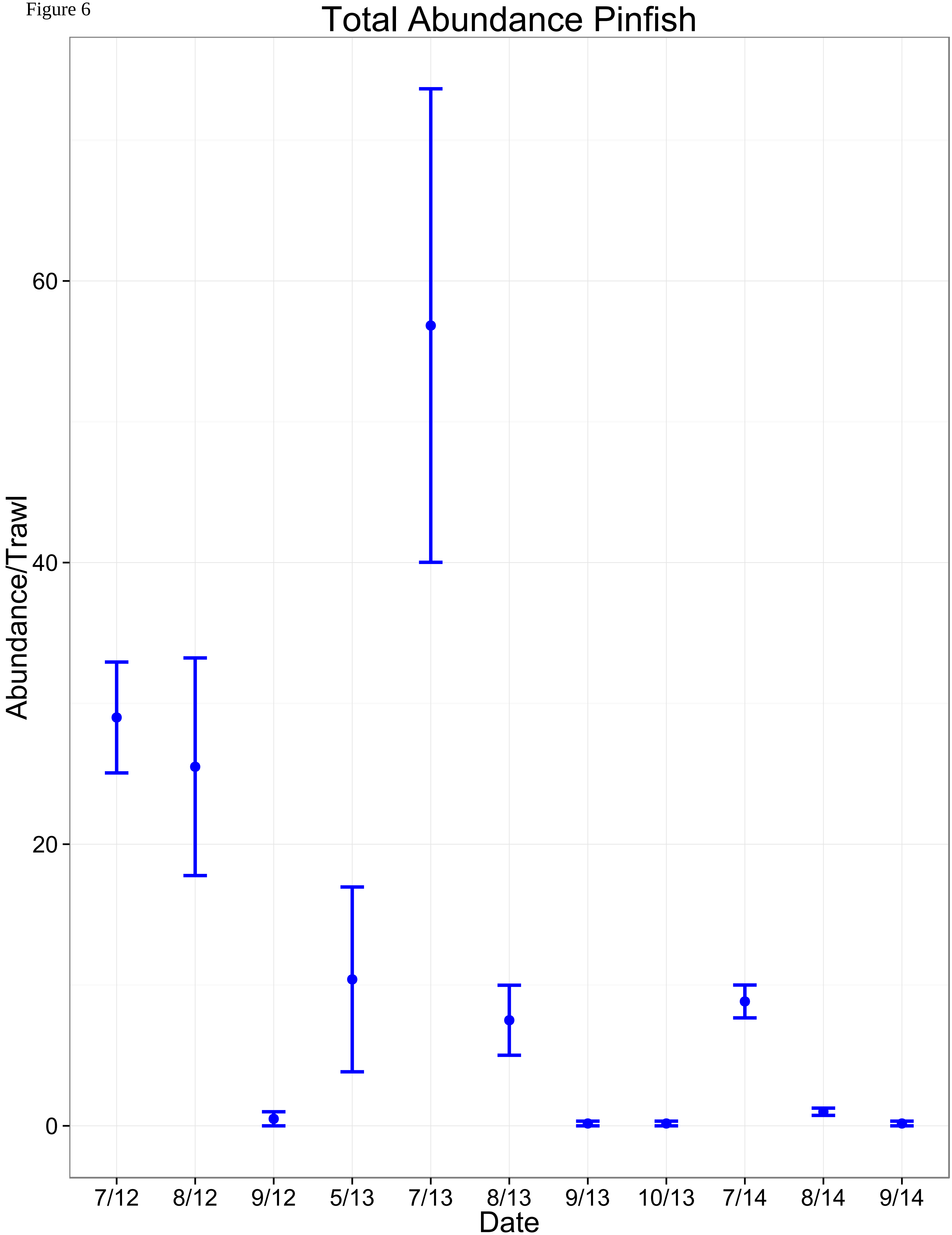
South Bay
Cobb Bay
Spider Crab Bay
Hog Island Bay
Seeded area (Ha)
Mapped area (Ha)
ND
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
Mapped 1−40% cover
Mapped 41−100% cover
Seeded area

Figure 5



Total Abundance of all Predators
300
200
100
0
Abundance
05
07
08
09
10
Month
factor(Year)
2012
2013
2014

Figure 6



Total Abundance Pinfish
Abundance/Trawl
60
40
20
0
7/12
8/12
9/12
5/13
7/13
8/13
9/13
10/13
7/14
8/14
9/14
Date

Figure 7

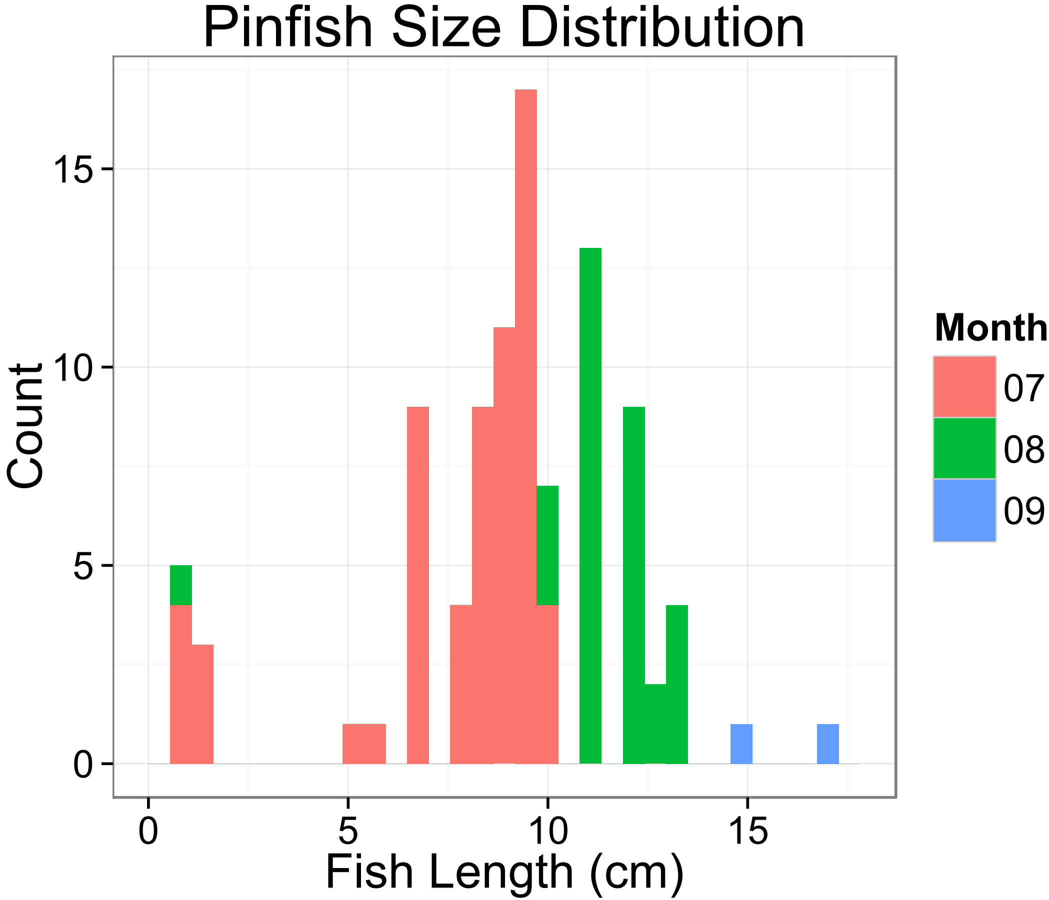
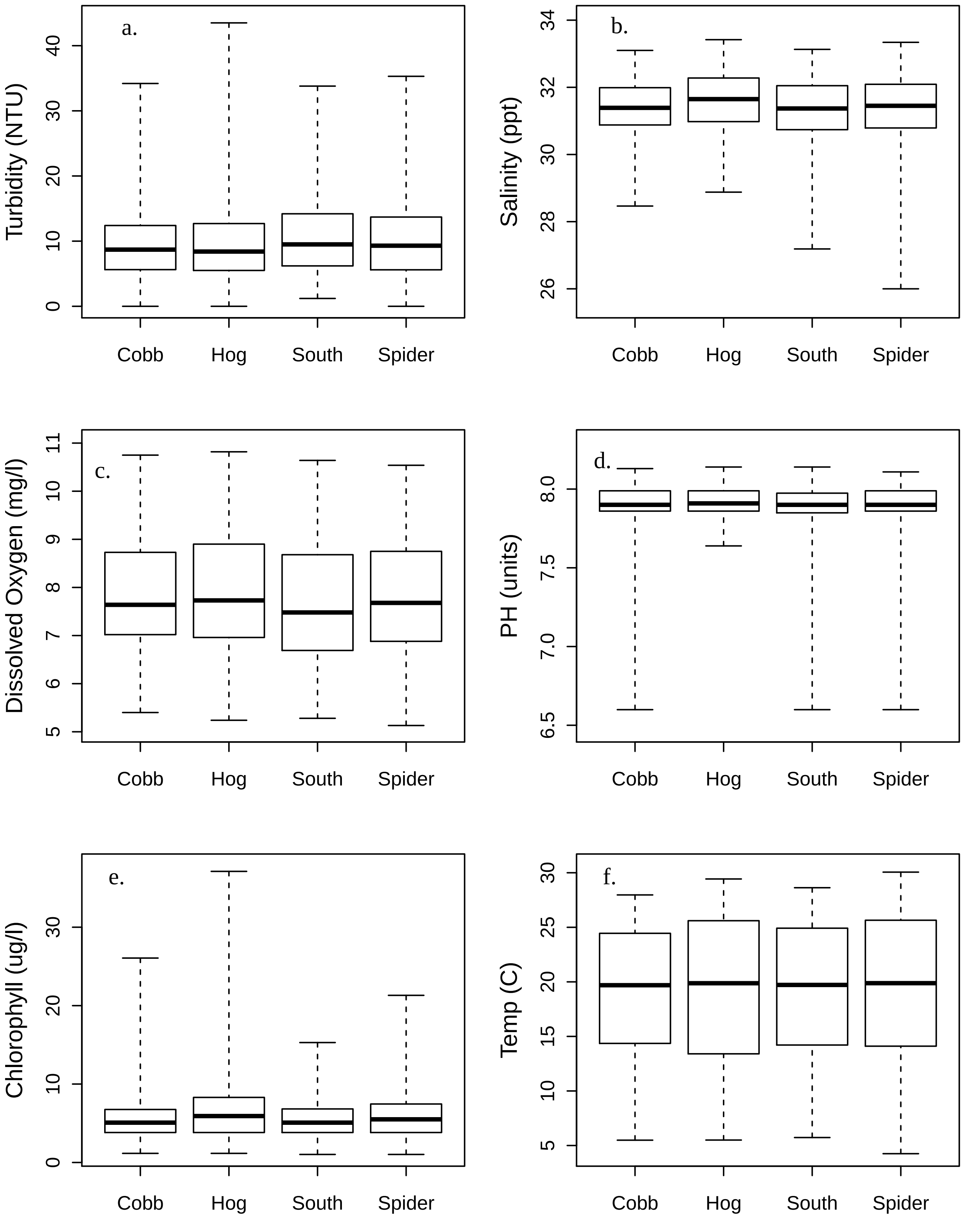

Pinfish Size Distribution
Count
15
10
5
0
0
5
10
15
Fish Length (cm)
Month
07
08
09

Figure 8


a.
Turbidity (NTU)
0
10
20
30
40
Cobb
Hog
South
Spider
b.
Salinity (ppt)
26
28
30
32
34
Cobb
Hog
South
Spider
c.
Dissolved Oxygen (mg/l)
5
6
7
8
9
10
11
Cobb
Hog
South
Spider
d.
PH (units)
6.5
7.0
7.5
8.0
Cobb
Hog
South
Spider
e.
Chlorophyll (ug/l)
0
10
20
30
Cobb
Hog
South
Spider
f.
Temp (C)
5
10
15
20
25
30
Cobb
Hog
South
Spider

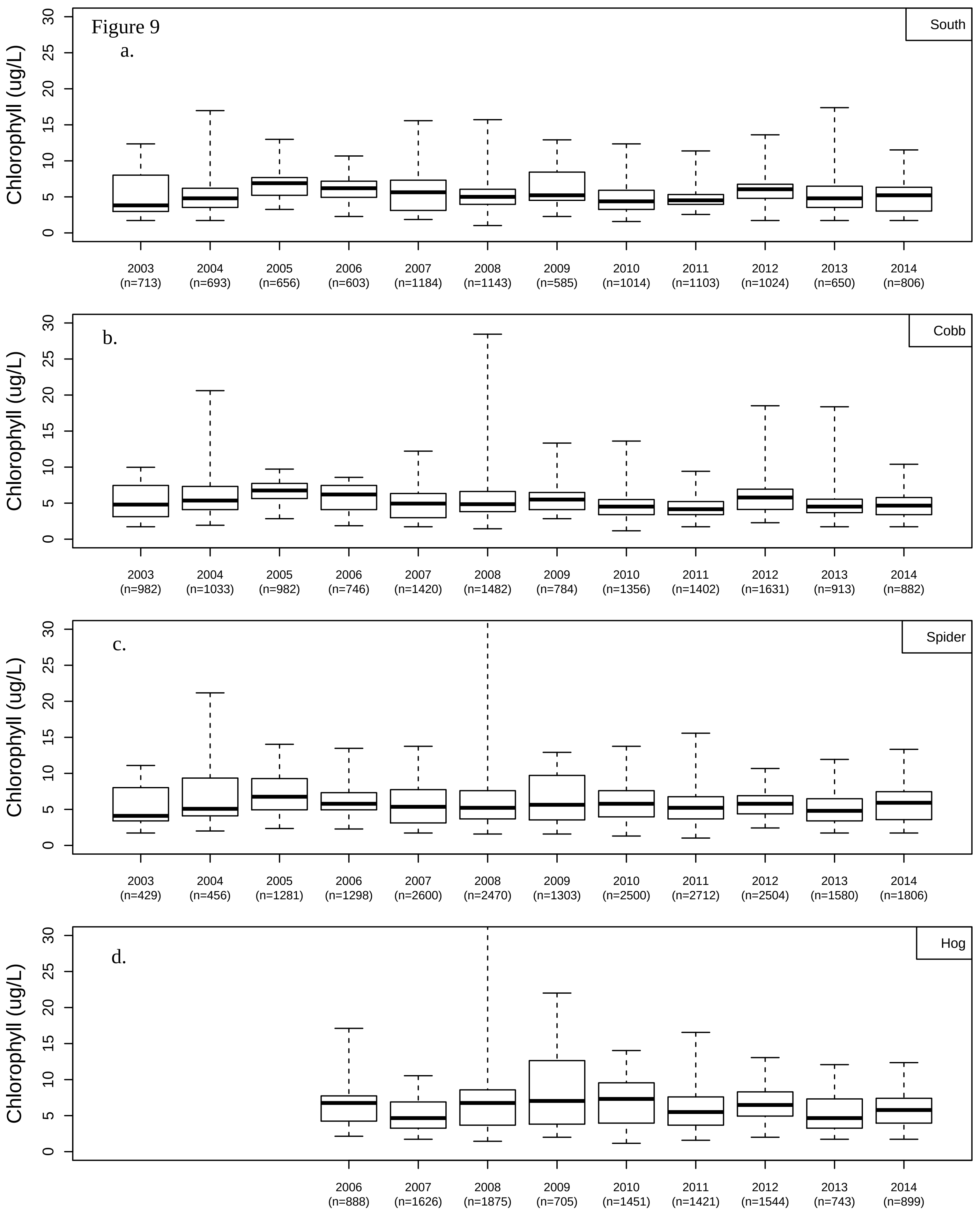


Figure 9
a.
South
b.
Cobb
c.
Spider
d.
Hog
Chlorophyll (ug/L)
0
5
10
15
20
25
30
2003 (n=713)
2004 (n=693)
2005 (n=656)
2006 (n=603)
2007 (n=1184)
2008 (n=1143)
2009 (n=585)
2010 (n=1014)
2011 (n=1103)
2012 (n=1024)
2013 (n=650)
2014 (n=806)
2003 (n=982)
2004 (n=1033)
2005 (n=982)
2006 (n=746)
2007 (n=1420)
2008 (n=1482)
2009 (n=784)
2010 (n=1356)
2011 (n=1402)
2012 (n=1631)
2013 (n=913)
2014 (n=882)
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)
2014 (n=1806)
2006 (n=888)
2007 (n=1626)
2008 (n=1875)
2009 (n=705)
2010 (n=1451)
2011 (n=1421)
2012 (n=1544)
2013 (n=743)
2014 (n=899)

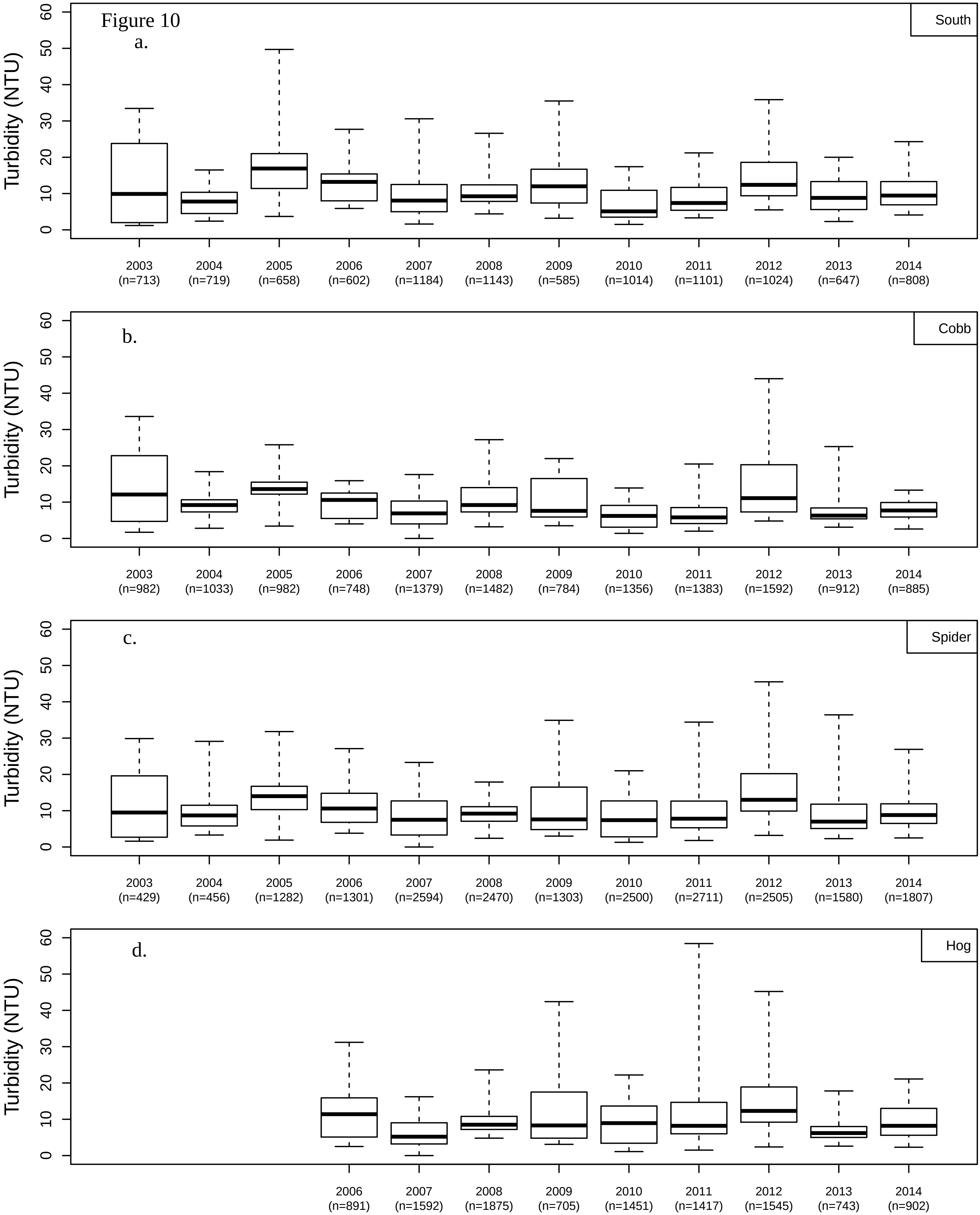
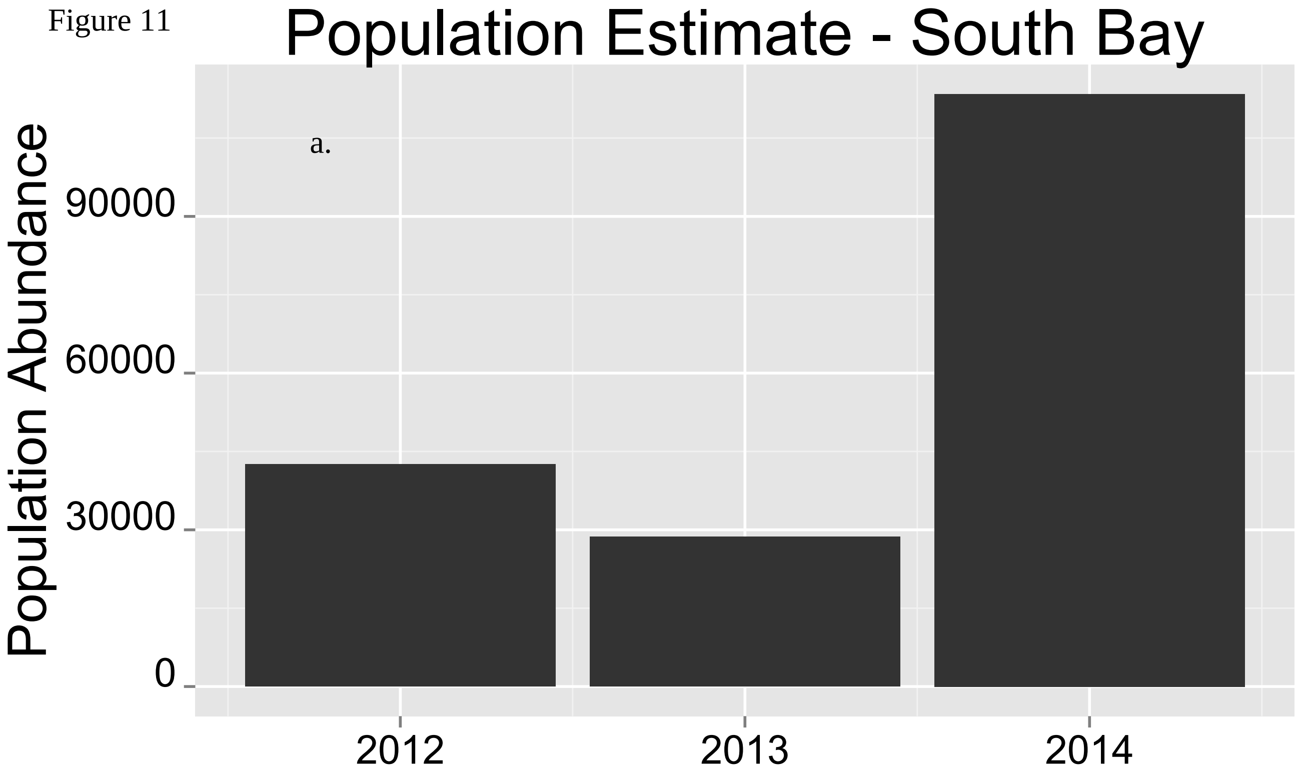
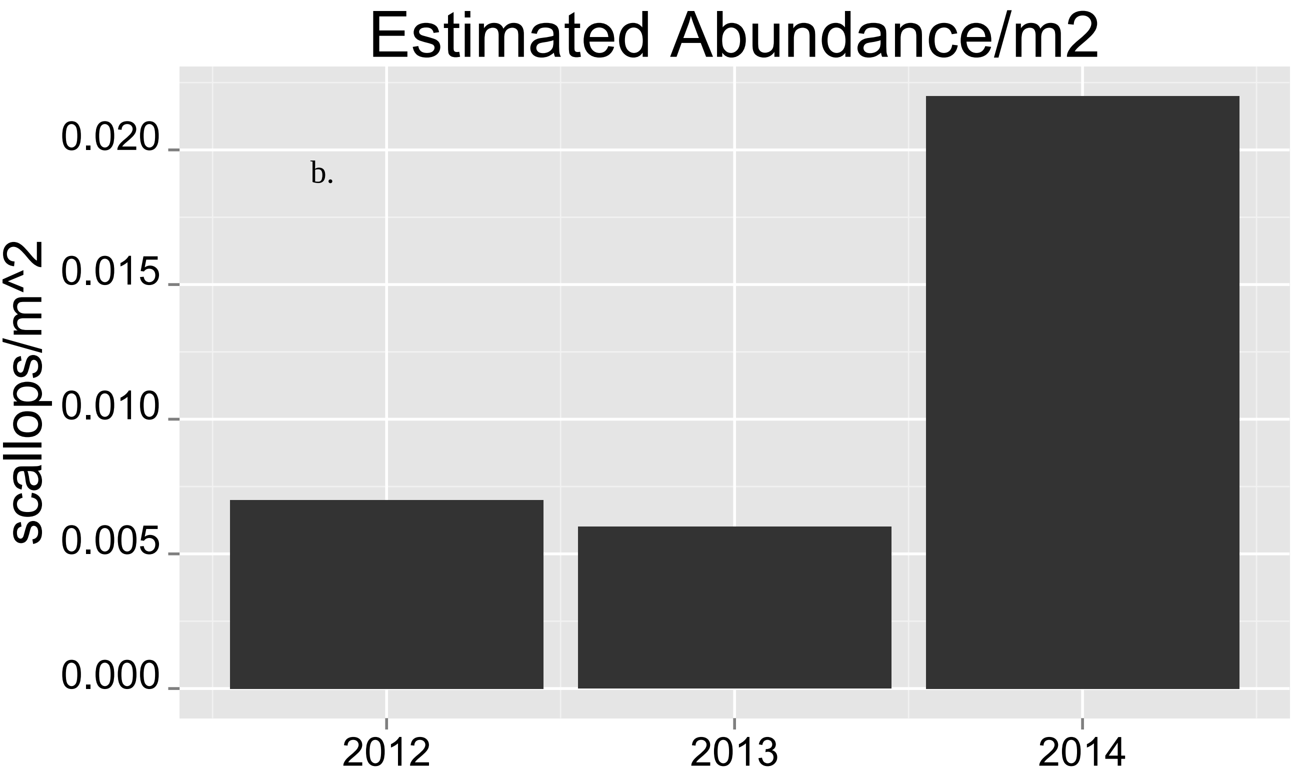


Figure 10
a.
South
b.
Cobb
c.
Spider
d.
Hog
Turbidity (NTU)
0
10
20
30
40
50
60
2003 (n=713)
2004 (n=719)
2005 (n=658)
2006 (n=602)
2007 (n=1184)
2008 (n=1143)
2009 (n=585)
2010 (n=1014)
2011 (n=1101)
2012 (n=1024)
2013 (n=647)
2014 (n=808)
2003 (n=982)
2004 (n=1033)
2005 (n=982)
2006 (n=748)
2007 (n=1379)
2008 (n=1482)
2009 (n=784)
2010 (n=1356)
2011 (n=1383)
2012 (n=1592)
2013 (n=912)
2014 (n=885)
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)
2014 (n=1807)
2006 (n=891)
2007 (n=1592)
2008 (n=1875)
2009 (n=705)
2010 (n=1451)
2011 (n=1417)
2012 (n=1545)
2013 (n=743)
2014 (n=902)

Figure 11


Population Estimate - South Bay
a.
Population Abundance
90000
60000
30000
0
2012
2013
2014


Estimated Abundance/m2
b.
scallops/m^2
0.020
0.015
0.010
0.005
0.000
2012
2013
2014