Final Report

To

Virginia Coastal Zone Management Program
National Oceanic and Atmospheric Administration

By

The Virginia Institute of Marine Science
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FY2014 Task 11 Eelgrass and Bay Scallop Restoration in the Seaside Bays of Virginia.
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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beds followed by a significant hurricane in 1933 that likely eliminated the remaining populations (Orth et al. 2006, unpublished data).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*, which supported a significant commercial fishery prior to these events and it 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 bays 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 through 2014.

The goal of this project was to continue the enhancement of eelgrass and the bay scallop to these coastal bays. Specific objectives of the FY 2014 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 FY2013 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 (VCR) 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 2015. 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 and Cobb Bays.

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, 2015, 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 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, 2015, eelgrass seeds were hand broadcast from a boat into pre-determined un-vegetated plots in Spider Crab Bay (Figure 2). Plot size was 0.4 ha (one acre) and seed density was 150,000 seeds per plot.

Germination rates of seeds collected in 2015 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, 2016, 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

Aerial photography of the coastal bays was conducted on May 26, 2015. The favorable conditions required to fly an aerial survey mission over these bays were as follows: 1. specified tidal stage (+/- 60 minutes of low tide); 2. plant growth season (peak biomass); 3. sun angle (between 20-40°); 4. atmospheric transparency (cloud cover less than 10%); 5. water turbidity (edge of grassbeds should be visible); and 6. wind (less than 10 kts) (Dobson et al. 1995). 2015 was the first year since 2012 when all of these conditions could be met to successfully conduct the aerial surveys of the coastal bays.

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 were 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-2015-03-15-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 2014 reporting period (October 1, 2015- Sept 2016). Broad spatial patterns in water quality were documented using continuous underway sampling (DATAFLOW) in 2015 and 2016 as in previous years (this effort commenced in 2003 and has been conducted annually, Orth et al. 2013) (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 described in this report were successfully completed at monthly intervals from October 2014 through September 2015, excluding the December-February period.

Scallop Seed Production

Broodstock for hatchery production of seed scallops were maintained in the field nursery and grow out cages kept in the South Bay grass beds. These cages allow for not only growing scallops for release and maintaining broodstock, but also promote some in situ spawning of scallops in the cages. 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 initiates in the adult scallops held in South Bay with increasing spring water temperatures, and is monitored by the field crew on maintenance visits. Several weeks prior to spawning, broodstock scallops were brought to the Castagna Shellfish Research Hatchery at the VIMS Eastern Shore Laboratory in Wachapreague. Broodstock were held there in tanks of filtered seawater and fed mixed cultured micro algae unitl gametes were ripe. Adults are then induced to spawn by a thermal shift. Fertlized eggs are collected by sieve from the spawning table and transferred to a conical tank. Hatched larvae are fed cultured micro alage through the free-swimming phase, approximately 9 days.

Larvae competent for settlement are collected by sieve and transferred to flowing seawater nursery tables fed a diet of natural phytoplankton from Wachapreague Channel. Juveniles are gown in this system for 4-6 weeks until >2 mm in size, permitting them to be transferred to 2 mm mesh bags for deployment in field grow out cages maintained in South Bay. Monthly maintenance tracks growth, cleans fouling from mesh and cages, and divides the scallops into larger mesh sized bags as they grow to avoid overcrowding. Scallops are regularly measured for growth and mortality assessed during these population splits and maintenance visits.

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 on the need to maximize survival, especially during summer months when predation rates are high, and on fertilization efficiency by providing for critical densities for *in situ* spawning

success. The cages are constructed of vinyl coated wire screening with 1 inch square mesh openings. The design is widely used for bottom culture of caged oysters. Two hundred adult scallops are place in plastic mesh bags (¼ inch to ½ inch mesh) and two bags are placed in each cage. The cages and bags require periodic cleaning by power washing at VIMS ESL, and fouled cages are swopped out with cleaned cages for this purpose.

Assessment of Wild Adult Scallop Populations

As in previous years we utilized diver surveys, targeting adult scallops that reside on the benthos within the eelgrass beds. These surveys were conducted by randomly selecting 320 point locations across the following three coastal bay regions: Cobb Bay, South Bay, and Southern South Bay (Figure 3.). Each of these regions was divided into 4 sub-regions containing the sample locations (Figure 3). At each of these sample locations one of five divers swam one of 5 transects arranged in a stellate pattern about the anchored research skiff. During each swim they randomly placed a 1 m^2 quadrat in 10 locations and they thoroughly search the area for adult scallops by touch as visibility was often poor. Overall, 16000-m^2 quadrats (about 4 acres) of bottom were sampled within the three bays. 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 for the grassbed. For comparison across the grassbeds, scallops per meter squared are also presented.

RESULTS

Eelgrass Seeding

In 2015, seeds were broadcast into 42 one acre (0.4-ha) plots in Spider Crab Bay (Figure 2) at a density of 150,000 seeds per acre for a total of 6.3 million seeds (Table 1b). Through 2015, 68.3 million seeds have been broadcast into 202 ha (499 acres) (Tables 1a, b, Figures 4, 5).

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 2015 was 2.2% (range of 0 – 6.3%). The laboratory mean germination rate of seeds assessed as viable was 68% with a range of 35 – 95% confirming that the seeds we dispersed were largely viable seeds.

Meadow Expansion and Development

In 2015 we mapped a total of 145 ha in Hog Island Bay (Figure 6 a.), 233ha in Spider Crab Bay (Figure 6 b), 588-ha in Cobb Bay (Figure 6 b), and 1541-ha in South Bay (Figure 6 c) for a total of 2508-ha total which is an increase of 629.5-ha from our last complete mapping effort of 2012, an increase of 33.5%.

Finfish

Over the years of our predator sampling total abundance of fishes is highest in the summer months, most notably in July (Figure 7). Pinfish *Logodon rhomboids*, a historically more tropical species, has been very abundant in our samples. The highest abundance recorded since the inception of our trawl survey in 2012 was in June, 2015 with a mean of over 150 individuals per trawl (Figure 8). We also see a shift in overall length of pinfish from a mean of 5-cm in June to 9-cm in July to 12-cm in August (Figure 9).

Cumulative fish species (β) richness consists of 40 taxa for the sampling years of 2012 – 2015. A full list of these species with the cumulative numbers sampled can be seen in Table 2.

Water Quality

Dataflow cruises were successfully completed at monthly intervals from March 2015 through November 2015. Figure 10 presents box plots (median, 25th and 75th percentile and the minimum and maximum of the lower 99% of the data) for each of the restoration areas during the March-November 2015 SAV growing season. Temperature medians were nearly identical at 20 to 20°C among all the sites (Figure 10 f). Median salinities again were very similar (31.4 to 31.6) at all sites, however, salinities occasionally reached lower levels at South and Spider Crab bays (Figure 10 b). Similarly dissolved oxygen (Figure 10 c) and pH levels (Figure 10 d) were very similar across the bays in 201% although the slightly lower pH observed at Cobb, South and Spider Crab sites were not observed at Hog Island Bay. Turbidity medians ranged between 8.6 NTU at Hog Island to 9.5 at South Bay (Figure 10 a). 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 4.9 and 5.1 µg/l at South and Cobb Bays, increasing to 5.6 at Spider Crab and 6.1 at Hog (Figure 10 e). These differences among sites have been consistent over recent years.

Figure 11 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 2003-2015 restoration project period. Overall, the pattern of lower median levels of chl-a found in 2015 in Cobb and South Bays were consistent over the entire time period with typical annual concentrations of 5.0 and 5.2 µg /l. 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 11 d) consistently had the highest levels of chl-a (µg /l) compared to Cobb (Figure 11 b) and South (Figure 11 a) which have remained the lowest of the restoration bays at 5.0 and 5.2 compared to 5.5 and 6.1 at Spider Crab and Hog Island (Figures 11, c and d).

Figure 12 a – b, 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 2003-2015 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 again showed similar patterns in median annual turbidity throughout the project period. Elevated turbidities were especially evident in 2006 and 2012 when median levels exceeded 11 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. 2015 levels were near the long term medians at each site indicating a very average year. Overall Cobb Island Bay (Figure 12 b.) typically has had the lowest long term turbidity at 7.9 NTU with South Bay the highest at 9.5 (Figure 12 a.). For this coastal bays region we have calculated that the seasonal light requirements for seagrass growth in this region are approximately 10 NTU or lower. Therefore over time all the sites typically have suitable seasonal turbidities for plant growth to the seagrass

restoration depths being used here (Figures 12 a – d). Years 2006, 2009 and 2012 have been above that threshold suggesting that significant year-to-year variability is occurring. In recent years (2013-2015) turbidities have been consistently at or below the long term median of 5.5 NTU.

Scallop Seed Production, Grow out, and Brood stock

Seven separate scallop spawns were conducted in the research hatchery on May 5, 12, 13, 15, 18, 19, and 26, 2015. Of these seven spawns, four produced larvae that were cultured until development of eye spots in the pediveliger stage. These efforts yielded a 6% survival from fertilized egg until pediveliger stage. At the end of the culture period, 4.44 million larvae were transferred to the ESL land-based nursery. Juveniles were reared in the nursery for six weeks. A total of 447,493 juveniles (10% survival) came out of the land-based nursery, 240,000 of which were placed into fine mesh spat bags and deployed in cages in the grass beds of South Bay on June 29. The remainder was free-released into the grass beds. On July 24, 2015 200,000 juvenile scallops were bought from J.C. Walker Bros. hatchery produced from VIMS-ESL broodstock scallops. These juveniles were immediately transported to South Bay and divided into 40 mesh bags divided throughout 10 cages.

Five spawns were conducted in the late summer of 2015 on August 4, 5, 7, 10, and 13. Mortality was highest (~93%) between Day 0 of culture and Day 2 of culture as the fertilized eggs are developing into free-swimming D-stage larvae. At the end of the culture period 358,000 larvae were placed in the land-based nursery, resulting in 1% survival from Day 0 to Day 10 of culture in the research hatchery. On September 30, count estimates from the land based nursery tables were obtained. 20,000 scallops were deployed in 3mm mesh bags contained within cages in the South Bay grass beds. 20,000 additional juveniles were deployed directly into the grass beds as they were too small to be retained in the grow-out bags. This resulted in a survival of 6% through the six-week nursery period.

For the year, 362,000 juvenile scallops and 90,400 adults were released to the grassbeds, for a total of 452,400 individuals.

Assessment of Wild Scallop Population

Diver surveys of 1354 acres within the South Bay grassbed during July 2015 yielded an estimated population of 104,000 scallops. This is down from the 113,000 estimated population size in 2014 (Figure 13 a) but the difference is not statistically significant so there is essentially no change. From 2013 to 2014, however, there was a highly significant increase in scallop abundance from 28,000 in 2013 ($p<0.001$).

Most notably, in 2015 the sampling effort expanded to include another South Bay grassbed, south of the main bed, designated Southern South Bay, and another north of Sand Shoal Inlet called Cobb Bay (Figure 3). In each of these new locations we found surprisingly high numbers of scallops with an estimated population abundance of 54,000 in Southern South Bay and 84,000 in Cobb Bay (Figure 13 a) Therefore, on a scallops/m^2 basis, we estimate that there were approximately 0.019 scallops/m^2 in South Bay, 0.022/m^2 in Southern South Bay and 0.027/m^2 in Cobb bay (Figure 13 b).

We expect that each of these estimates represent an underestimate of the actual population size with the grassbeds since catch efficiency, though unknown, is likely less than 100%.

DISCUSSION

Eelgrass Bed Development

The use of seeds in the recovery of eelgrass in the Virginia coastal bays continued successfully in 2015. 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 42 1 acre plots in 2015. In the spring of 2015, for the subset of acre plots that we checked, we found that establishment rates were slightly lower than in 2014. The highest success rate for 2016 was 6.28% establishment whereas we observed rates as high as 17% in 2015.

Eelgrass continues to spread naturally as recorded in the 33.5% increase in aerial overage from our last baywide survey in 2012. The growth of eelgrass in new areas of these coastal bays as well as the expansion of the existing beds supports the concept that seeds are important is this expansion process and dispersal of flowering fragments with seeds is the primary dispersal mechanism for colonizing areas that are distant from any established beds. We anticipate that seagrass meadows will continue to expand both from our additional restoration effort using seeds but also dispersed seeds from established beds. The expansion of seagrass here in the coast al bays stands in stark contrast to what is being recorded in Chesapeake Bay (Lefcheck, et al., 2017)

Finfish

The high abundance of fishes in the summer months (Figure 7) is most likely a function of seasonal temperature that determines the timing of their arrival to the South Bay grassbeds. These data continue to help us to better understand the food web dynamics of the seaside grassbeds, and, more practically, they assist in more informed decisions regarding the timing of scallop releases. Using these data we continue 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, most prominently in June of 2015 (Figure 8).

In addition to their high summertime abundance, the ontological shift in the diets of pinfish make them of special concern for juvenile scallops (Figure 9). Small pinfish (<60mm) prefer small crustaceans until they reach a size of 60mm. From 61 – 120 mm they feed on larger benthic invertebrates including bivalve mollusks. Pinfish > 120 mm generally become omnivorous (Livingston 2003).

This ontological shift can be seen in Figure 9 and with the color-shaded factor of month it might also be inferred that this is the same population of pinfish as its mean size grows. 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. This is also in line with recent work by (Schmitt et al. 2016), where they found large numbers of pinfish in the predaceous size

range, in the month of 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 time the release of juvenile scallops so as to avoid high predation intensity by pinfish and other predators in the future.

Water Quality in the Virginia Coastal Bays

Water quality monitoring of the four restoration areas in 2015 indicates that, overall, mean water quality remained suitable 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. Both chlorophyll and turbidity concentrations in 2015 showed higher ranges at Hog Island Bay (Figure 10, a, e) for the second consecutive year (Figures 11 d and 12 d). Here restoration success has been lower. 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. Hog Island Bay has shown consistently higher ranges of suspended sediments than the other restoration bays suggesting that restoration success there may be more difficult. The overall lower concentrations of chlorophyll and turbidity since 2012 are positive for eelgrass populations. Because of the positive feedbacks between restored seagrass bed size and abundance and water quality which we have observed here and in other coastal systems, this, now three year overall improvement, is encouraging. Storms or other factors including warming climate, disease or man induced perturbations from aquaculture fishery activities or dredging could change this trajectory and these factors should be carefully monitored and in the case of man-made stressors, minimized as much as possible.

Scallop Restoration

Previous reports (FY11 Task 12, FY12 Task 11, FY13, 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. Anecdotal evidence continues to suggest these scallops are spreading beyond the release and in situ spawning sites. One change in our spawning strategy implemented this year was to use the wild scallops recovered during the annual census for broodstock, and thereby incorporation any selective pressures for survival in the system in our next cycle of production from the ESL hatchery.

The quantitative annual census suggests a loss in numbers of the wild population, which may in fact be due to intense predation by rays, which also created substantial numbers of feeding pits in the grassbeds dislodging *Zostera* plants. Despite this setback, we are confident that ultimately the population can reach sustainable levels. Expanding the seagrass habitat further will help us to create a sustainable population of scallops in the seaside bays of Virginia.

One encouraging aspect of our 2015 survey of adult scallops was that we observed significant populations in other Virginia seaside bays, notably Cobb and Southern South Bays (Figures 13a and 13b), demonstrating that bay scallops have spread beyond the areas in which they were originally stocked (South Bay), most likely due to their broadcast spawning. It is also

encouraging that our quantitative survey of adult scallops in South Bay showed a substantial increase in abundance in 2014 and 2015 compared to previous years, 2012 and 2013 (Figure 13a and 13b). This continues our proof of concept that enhancement of the bay scallop population can be achieved.

Though we did observe no significant increase from 2014 to 2015 the most likely explanation may have been the excessively cold winter with extensive sea ice in 2014. It is encouraging that despite this ice event *A. irradians concentricus* (the southern species) endured with numbers essentially unchanged for the year.

One of the bottlenecks to increasing the production of our scallop output are the high labor and space requirements for the cage rearing of scallops in in the field. In 2016, to ameliorate these issues, we explored other strategies including the utilization of several large holding tanks with flow through water in Oyster Harbor, VA, owned and operated by The Nature Conservancy's VCR office. There we raise scallop larvae to a suitable size for direct release into the grassbeds when predator abundance is low, most likely in the fall.

Overall, we are very encouraged by these early successes, however, in our best informed judgment, the standing stock of wild bay scallops has not reached a point at which we expect it will be self-sustaining. With an abundance of 0.02 scallops/m^2 (Figure 13b), we must achieve an order of magnitude higher population to be self-sustaining. Thus, as we move forward we will explore ways to improve our restoration strategy.

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Table 1a. Summary of eelgrass seed distributions for South and Cobb 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	4.2	11.2	0.4	28				
2015								
Total	11.7	35.5		96	5	15		49

Table 1b. Summary of eelgrass seed distributions for Spider Crab and Hog Island Bays (number of viable seeds distributed, total area seeded, size and number of plots seeded).

	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	3.5	9.2	0.4	23				
2015	6.3	16.8	0.4	42				
Total	47.8	133.3		357.0	3.8	18.2		58.0

Table 2. Species list of fauna collected during the South Bay trawl survey from 2012 – 2015.

Common Name	**Species**	**Total**
Silver Perch	*Bairdiella chrysoura*	3942
Pinfish	*Lagodon rhomboides*	1984
Atlantic Silverside	*Menidia menidia*	511
Northern Pipefish	*Syngnathus fuscus*	462
Blue crab	*Callinectes sapidus*	433
Pigfish	*Orthopristis chrysoptera*	250
Spot	*Leiostomus xanthurus*	218
Anchovy	*Anchoa mitchelli*	161
Sheepshead	*Archosargus probatocephalus*	128
Dusky Pipefish	*Syngnathus floridae*	53
Black Seabass	*Centropristis striata*	42
Gag Grouper	*Mycteroperca microlepis*	37
Toadfish	*Opsanus tau*	22
Spotted codling	*Urophycis regia*	21
Drum unid	*Drum unid*	18
Striped Burrfish	*Chilomycterus schoepfii*	10
Summer Flounder	*Paralichthys dentatus*	10
Tautog	*Tautoga onitis*	9
Silver Jennie	*Eucinostomus gula*	6
Spot	*Cynoscion nebulosus*	6
Northern Sennet	*Sphyraena borealis*	6
Bluefish	*Pomatomus saltatrix*	6
Northern Puffer	*Sphoeroides maculatus*	5
Sea Robin	*Prionotus*	5
Conger eel	*Conger oceanicus*	4
Blue Spotted Cornetfish	*Fistularia tabacaria*	3
Red drum	*Sciaenops ocellata*	2
Dasyatis americana	*Southern Sting Ray*	2
Spottail pinfish	*Diplodus holbrookii*	3
Spotfin Butterfly Fish	*Chaetodon ocellatus*	2
Striped blenny	*Chasmoides bosquianus*	1
Planehead filefish	*Stephanolepis hispida*	1
Grouper	*Myctoperca*	1
Spotted seatrout	*Anchoa sp.*	1
Northern Kingfish	*Menticirrhus saxatilis*	1
Mudcrab	*Panopeus sp*	1

Inshore Lizardfish	*Synodus foetens*	1
Mojarra	*Eucinostomus sp.*	1
Naked Goby	*Gobiosoma bosc*	1
Snowy grouper	*Epinephelus niveatus*	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. Map showing the 42 0.4-ha plots of Spider Crab Bay each of which received 100,000 eelgrass seeds in 2015.

Figure 3. Map showing the sample scheme for the 2015 adult scallop survey for each of the seagrass regions of Cobb Bay, South Bay and Southern South Bay. Yellow denotes the sampling sub-regions. Red dots indicate the randomly chosen survey locations.

Figure 4. Cumulative area of seeding (blue) and total area estimate from the aerial mapping (red) for all four seaside bays through 2015. Complete datasets indicated by green dots. Aerial survey data for all 4 bays were unavailable for 2005, 2013 and 2014 (dashed line).

Figure 5. 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 and 2015, seeds were only broadcast in Spider Crab Bay and aerial measurements were only available for South Bay in 2013. No aerial data was available in 2014).

Figure 6. Digital aerial survey data of *Zostera marina* beds for 2012 (green) and 2015 (yellow + green) for a. Hog Island Bay, b. Spider Crab and Cobb Bays and c. South Bay.

Figure 7. Total fish abundance/150-m trawl for the months of May (05) through October (10) for the years of 2012 through 2015.

Figure 8. Time series of the mean abundance of pinfish per 150-m trawl over the course of the survey period from 2012 through September 2015. The error bars indicate the standard error about the mean.

Figure 9. Histogram showing the number of pinfish as a function of fish length, with colors representing the factor month with red = June, green = July, blue = August and purple = September (Note – only the first 10 individuals per trawl were measured).

Figure 10. 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 2003-2015, and the same for (b) salinity (psu), (c) dissolved oxygen (mg/L), (d) pH, (e) Chlorophyll-a, and (f) Temperature (^{o}C).

Figure 11 a – d. 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 2003-2015.

Figure 12 a – d. 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 2003-2015.

Figure 13. Bar plots showing (a) the population estimate of adult scallops as estimated by the total seagrass bed area for South Bay (green) for the years of 2012 – 2015 and for Cobb Bay (orange) and Southern South Bay (blue) in 2015 and (b) the estimated number of scallops per meter squared for the same years and bays as a.

Figure 1

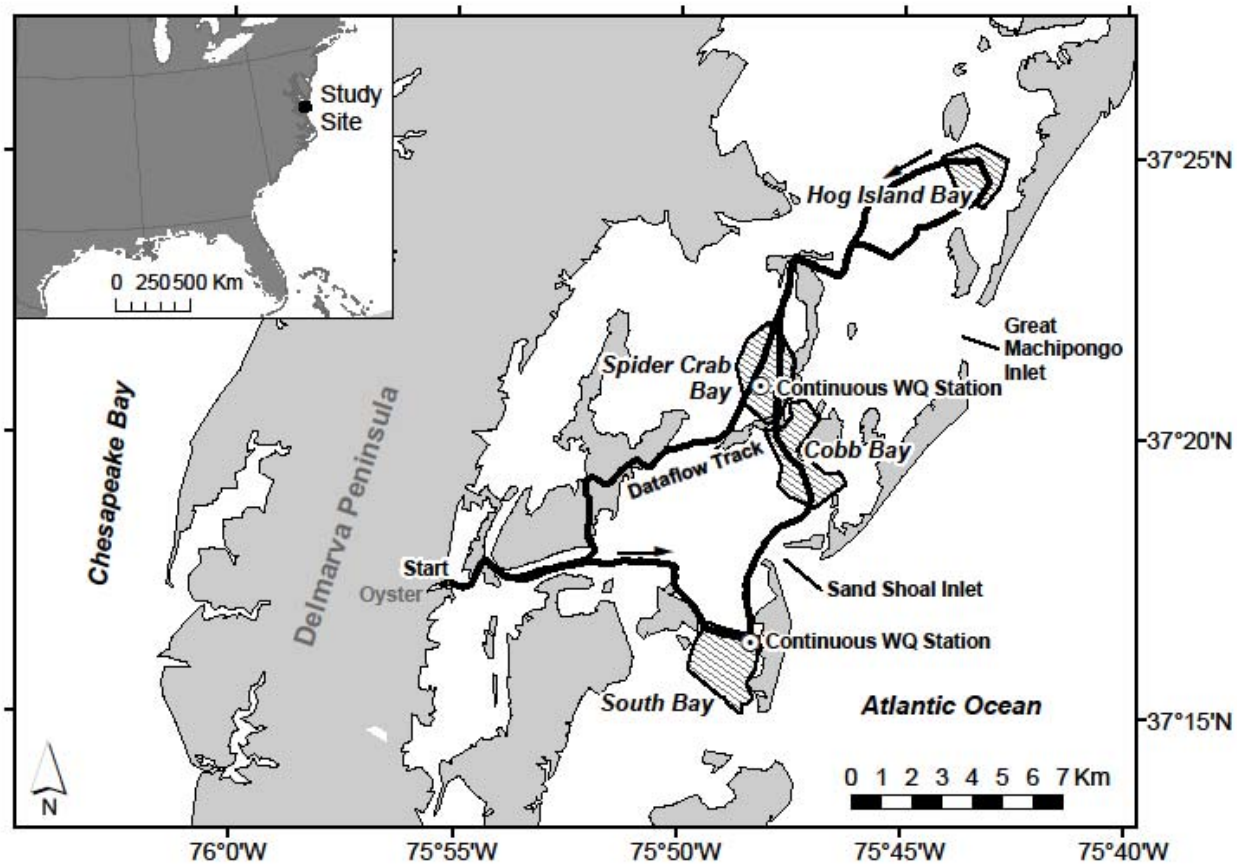

Study Site
0 250 500 Km
Chesapeake Bay
Delmarva Peninsula
Hog Island Bay
Great Machipongo Inlet
Spider Crab Bay
Continuous WQ Station
Cobb Bay
Dataflow Track
Start
Oyster
Sand Shoal Inlet
Continuous WQ Station
South Bay
Atlantic Ocean
0 1 2 3 4 5 6 7 Km
N
37°25'N
37°20'N
37°15'N
76°0'W
75°55'W
75°50'W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

Figure 2.

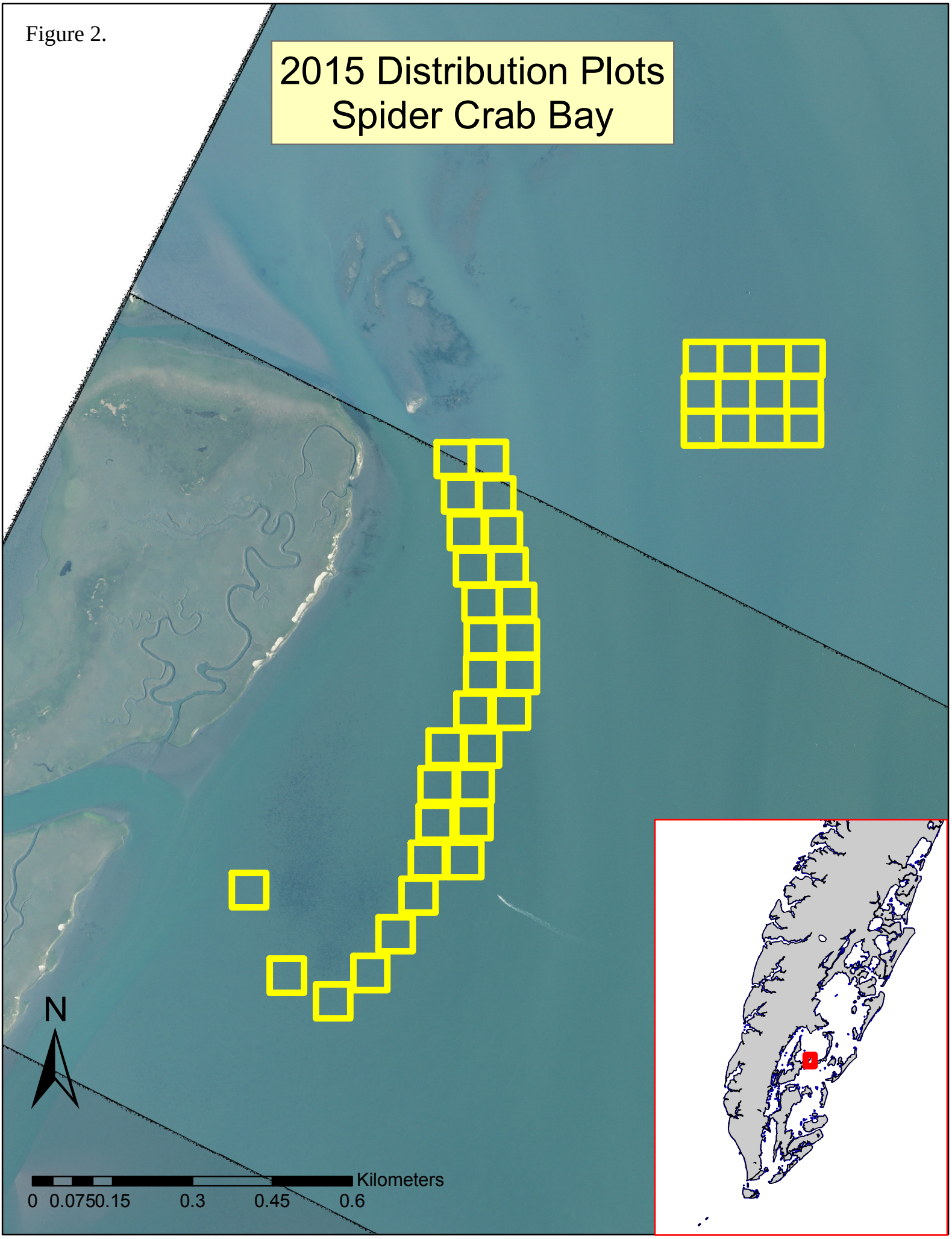
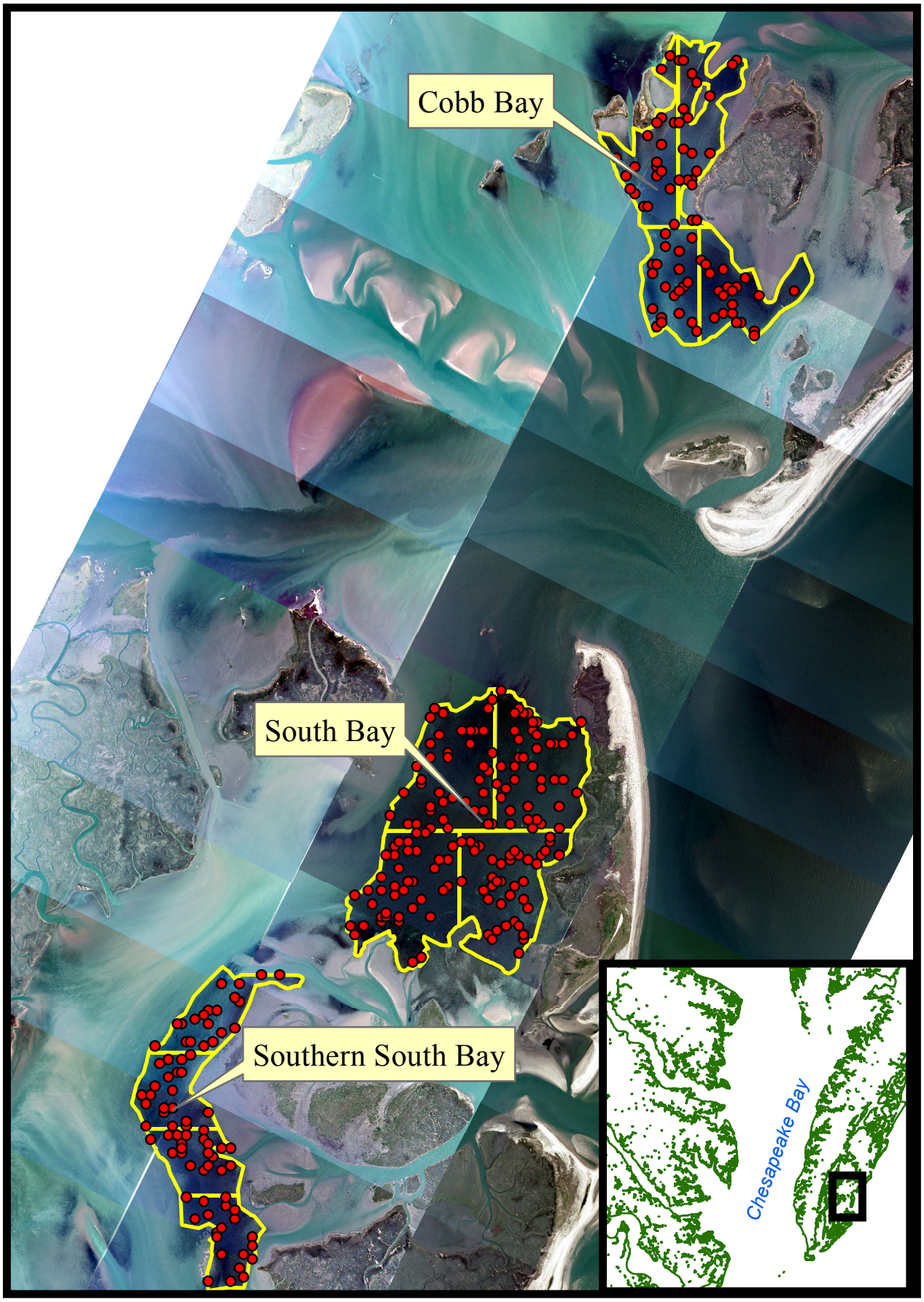

2015 Distribution Plots
Spider Crab Bay
N
Kilometers
0 0.0750.15 0.3 0.45 0.6

Figure 3.

Bay Scallop Sampling in Virginia's Coastal Bays



Kilometers

0 0.75 1.5 3 4.5 6

Figure 4.

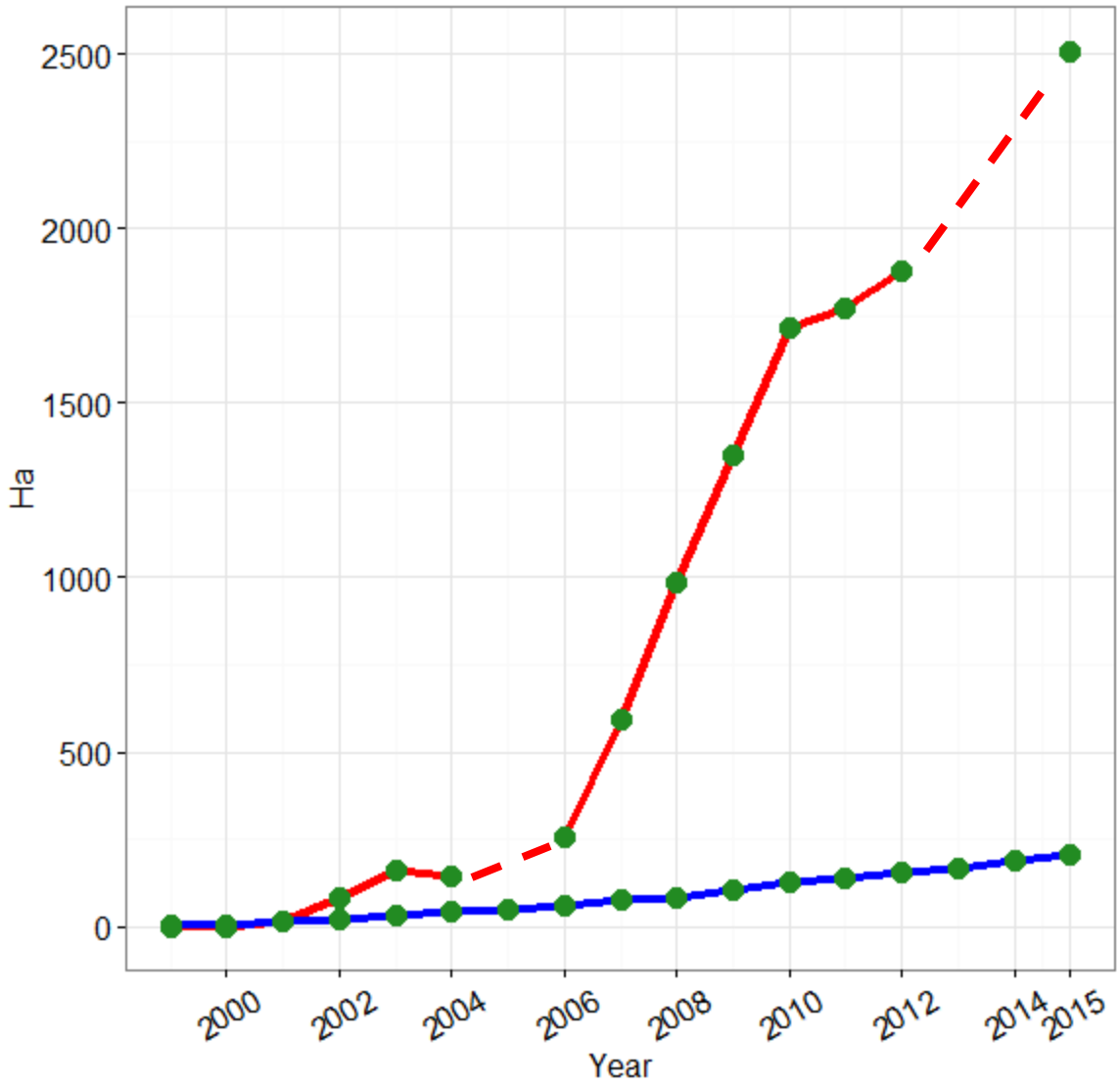

2500
2000
1500
1000
500
0
Ha
2000
2002
2004
2006
2008
2010
2012
2014
2015
Year

Figure 5.

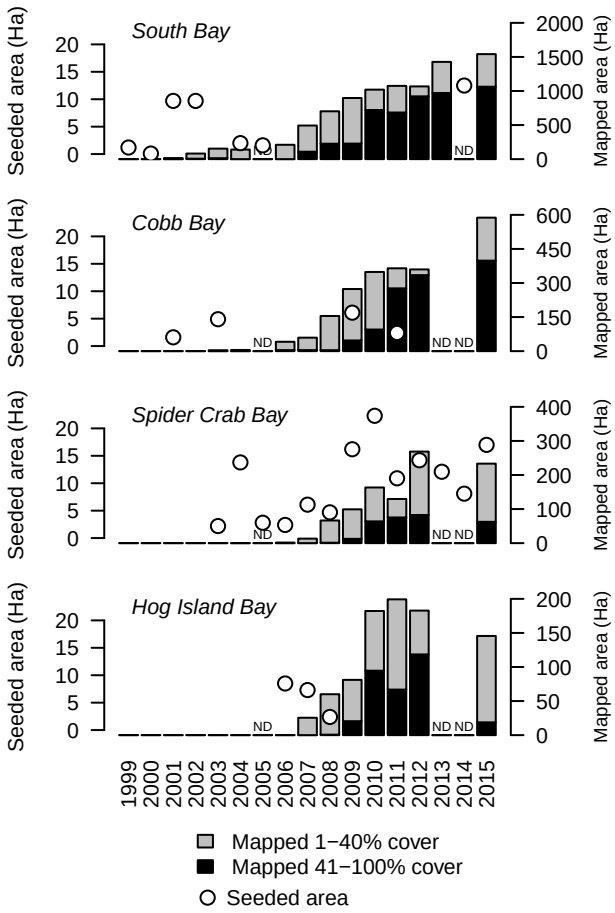

South Bay
Cobb Bay
Spider Crab Bay
Hog Island Bay
Seeded area (Ha)
Mapped area (Ha)
ND
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Mapped 1−40% cover
Mapped 41−100% cover
Seeded area

Figure 6a.

Hog Island Bay
2012 - 2015
SAV Coverage
N
0
0.225
0.45
0.9
1.35
1.8
Kilometers

Figure 6b.

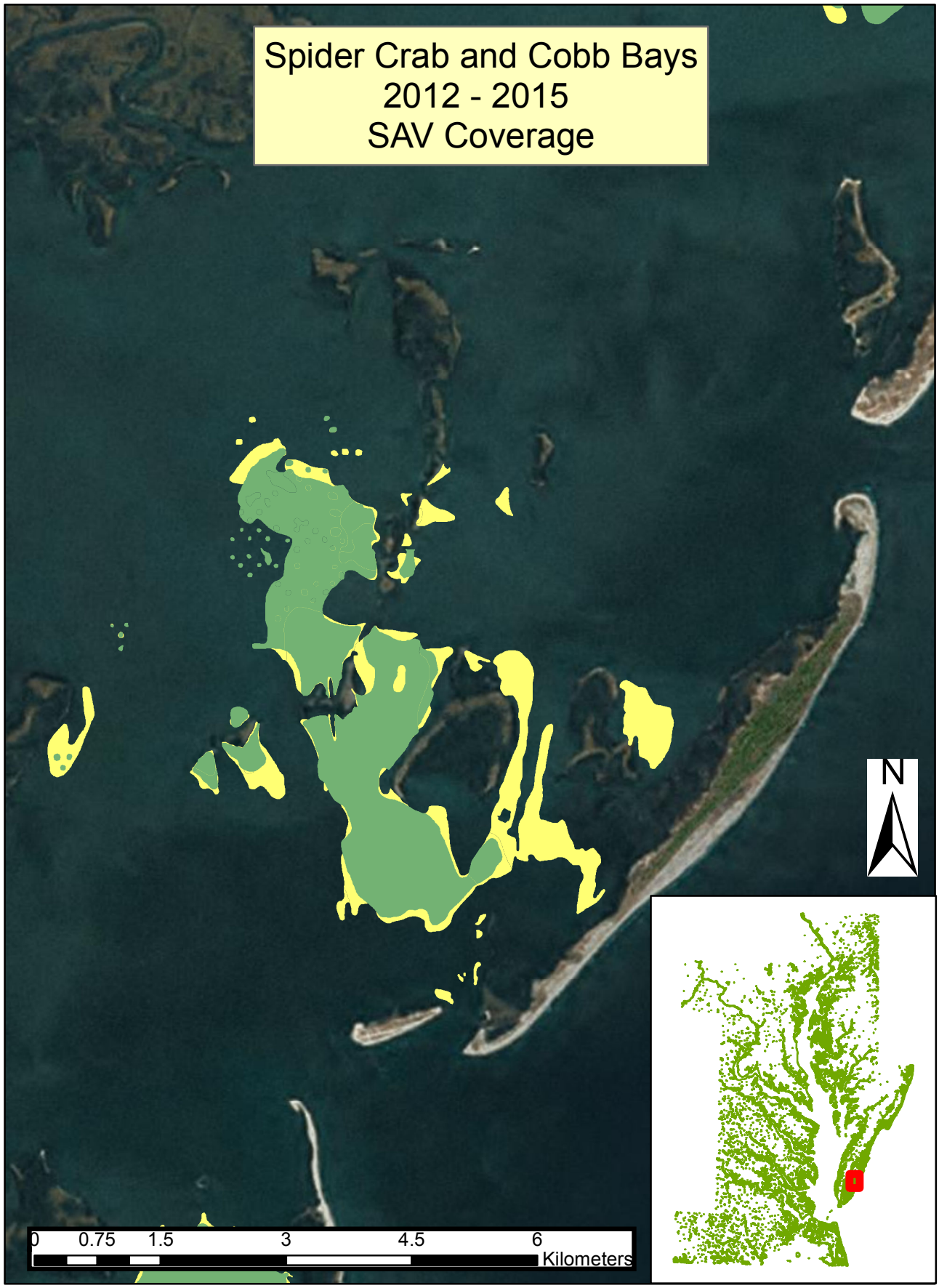

Spider Crab and Cobb Bays
2012 - 2015
SAV Coverage
N
0
0.75
1.5
3
4.5
6
Kilometers

Figure 6c.

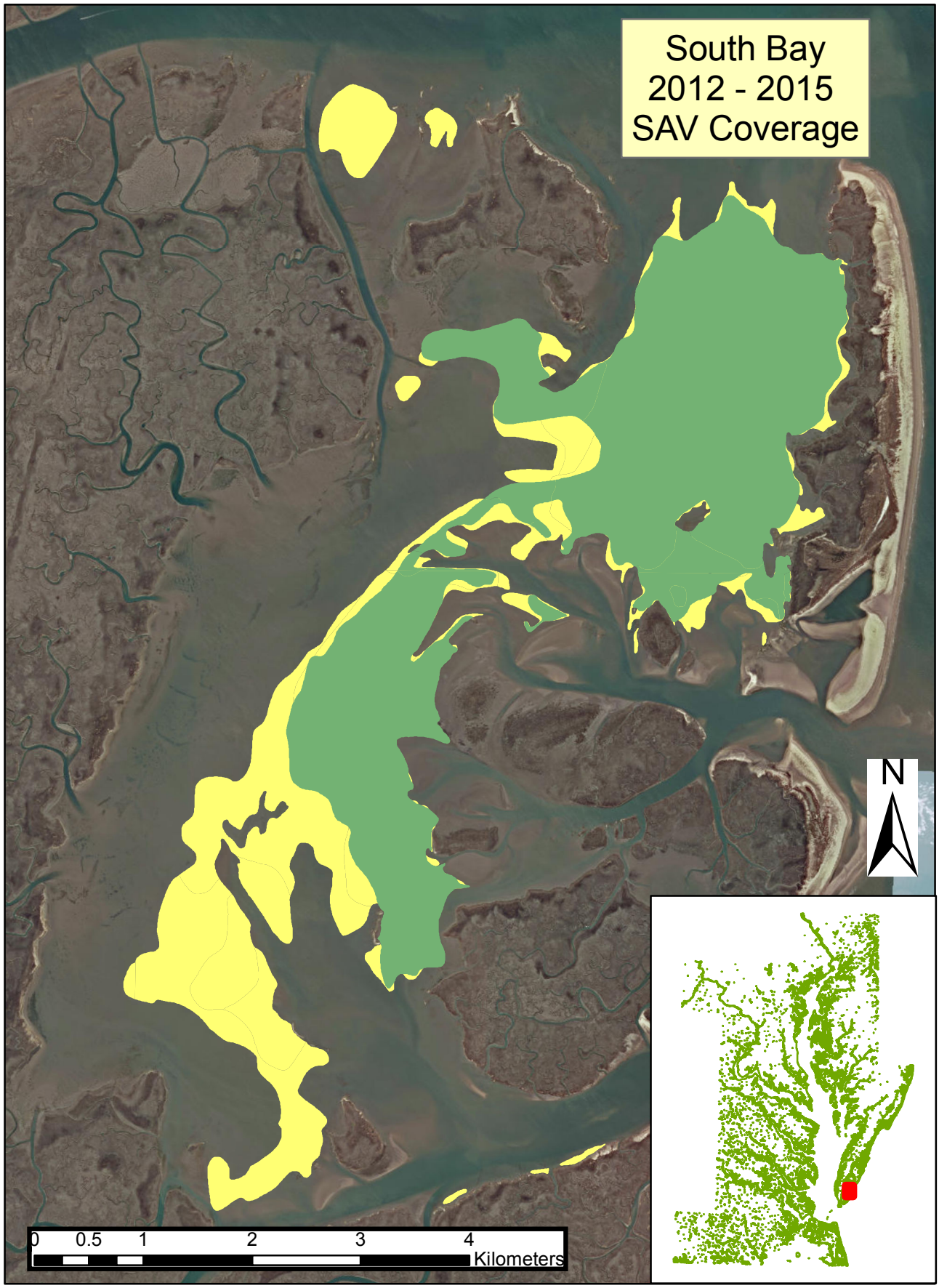


Figure 7.

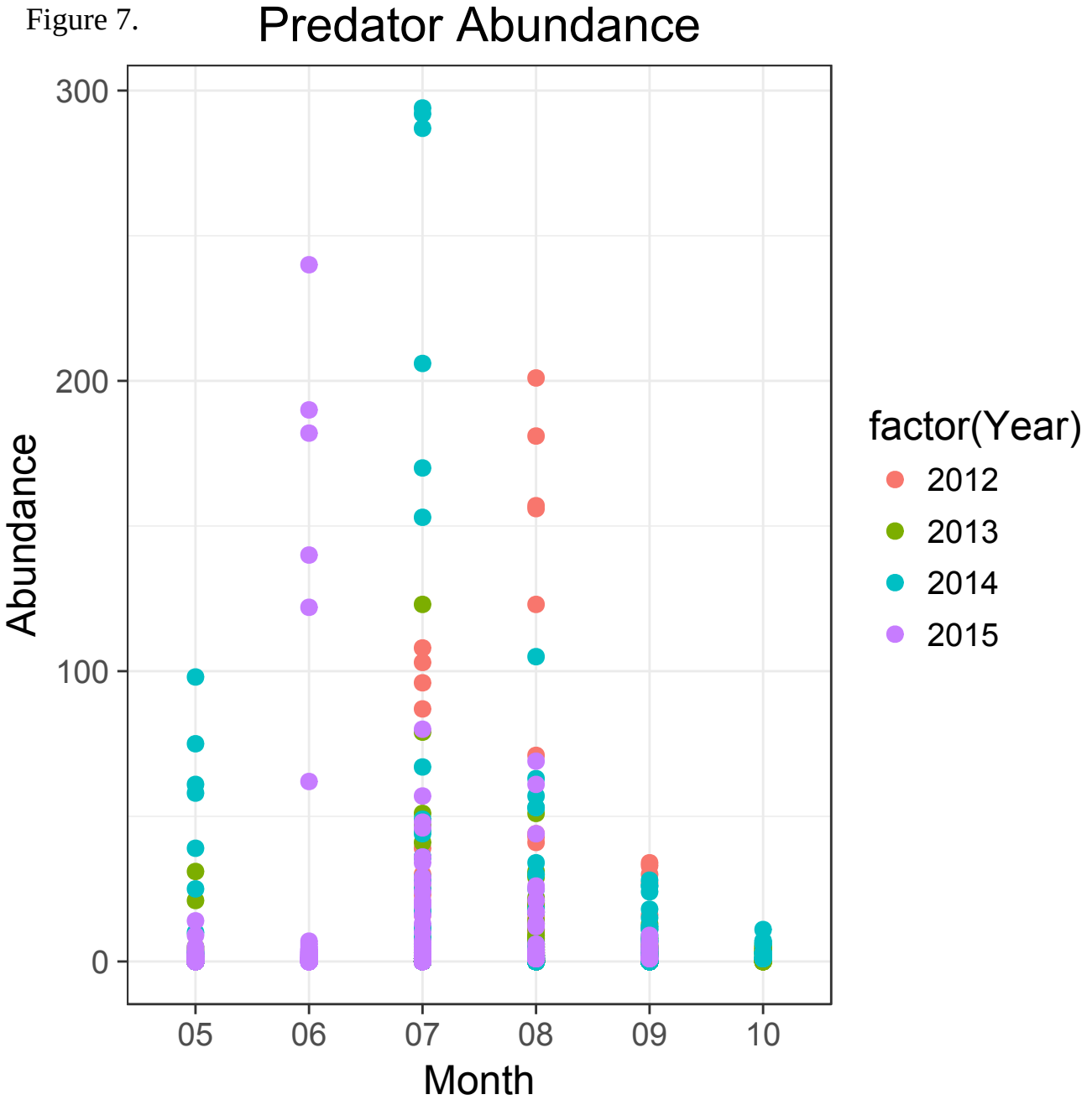

Predator Abundance
300
200
100
0
Abundance
05
06
07
08
09
10
Month
factor(Year)
2012
2013
2014
2015

Figure 8.

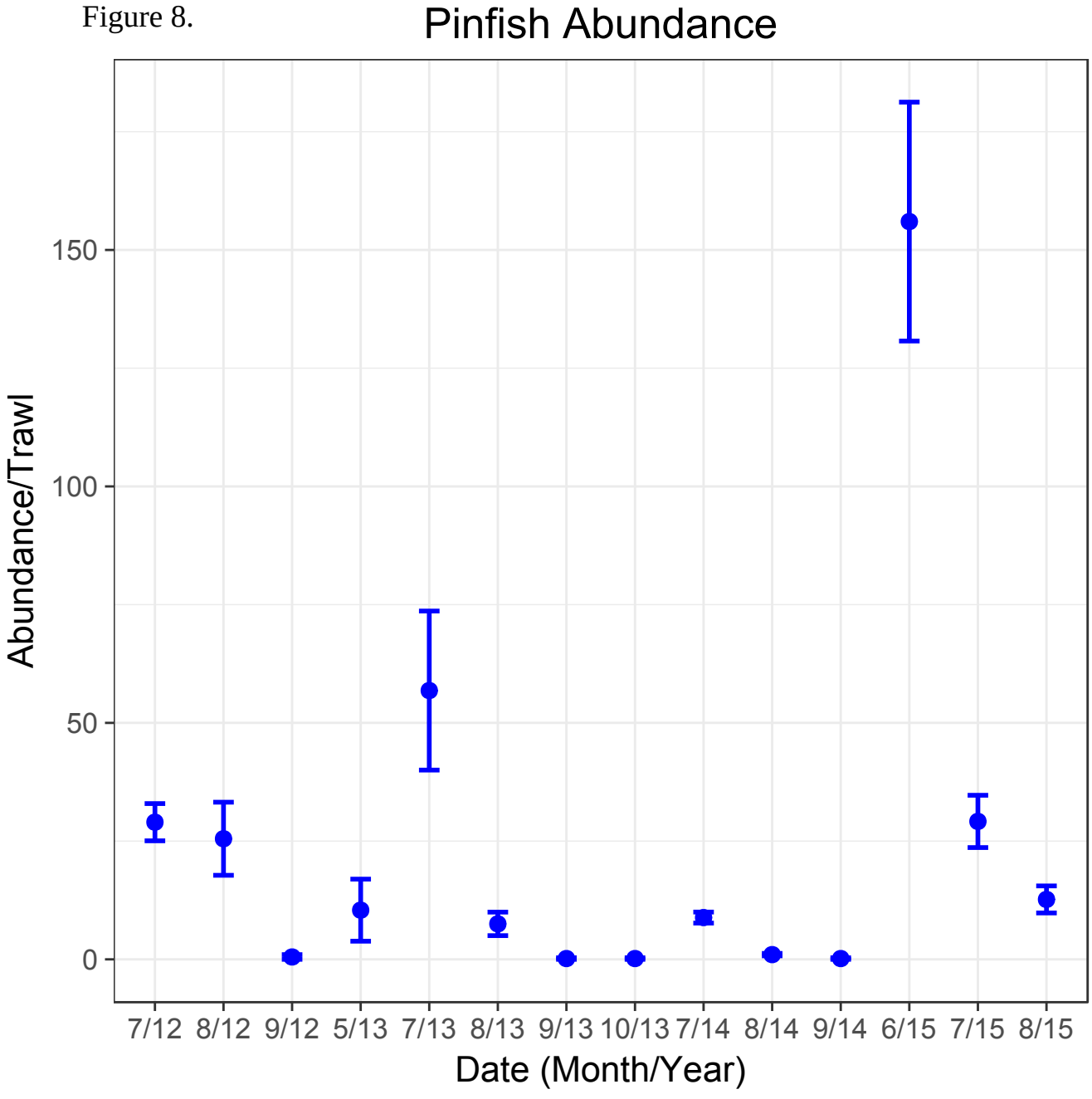

Pinfish Abundance
Abundance/Trawl
150
100
50
0
7/12
8/12
9/12
5/13
7/13
8/13
9/13
10/13
7/14
8/14
9/14
6/15
7/15
8/15
Date (Month/Year)

Figure 9.

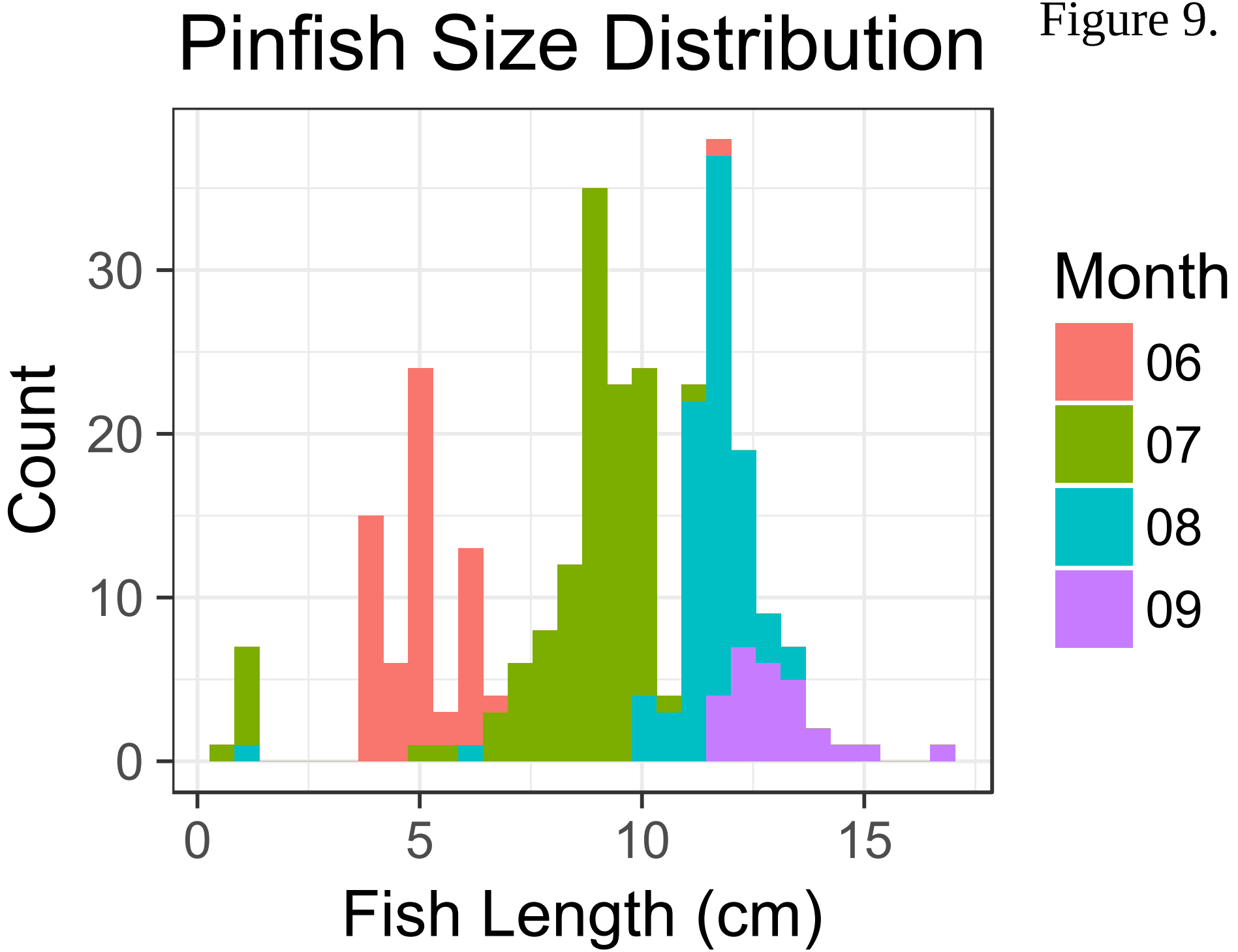
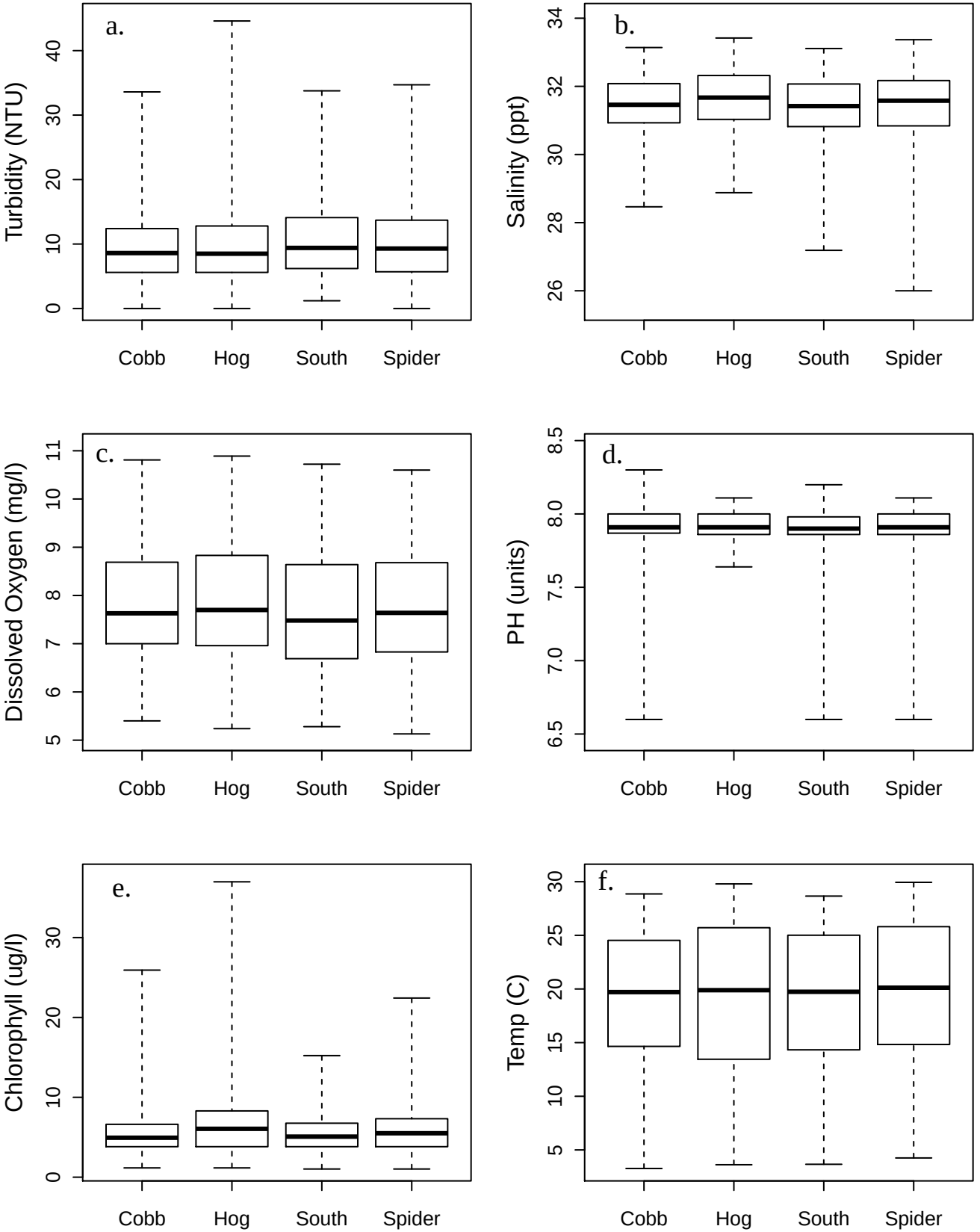

Pinfish Size Distribution
Count
30
20
10
0
0
5
10
15
Fish Length (cm)
Month
06
07
08
09

Figure 10.


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
8.5
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

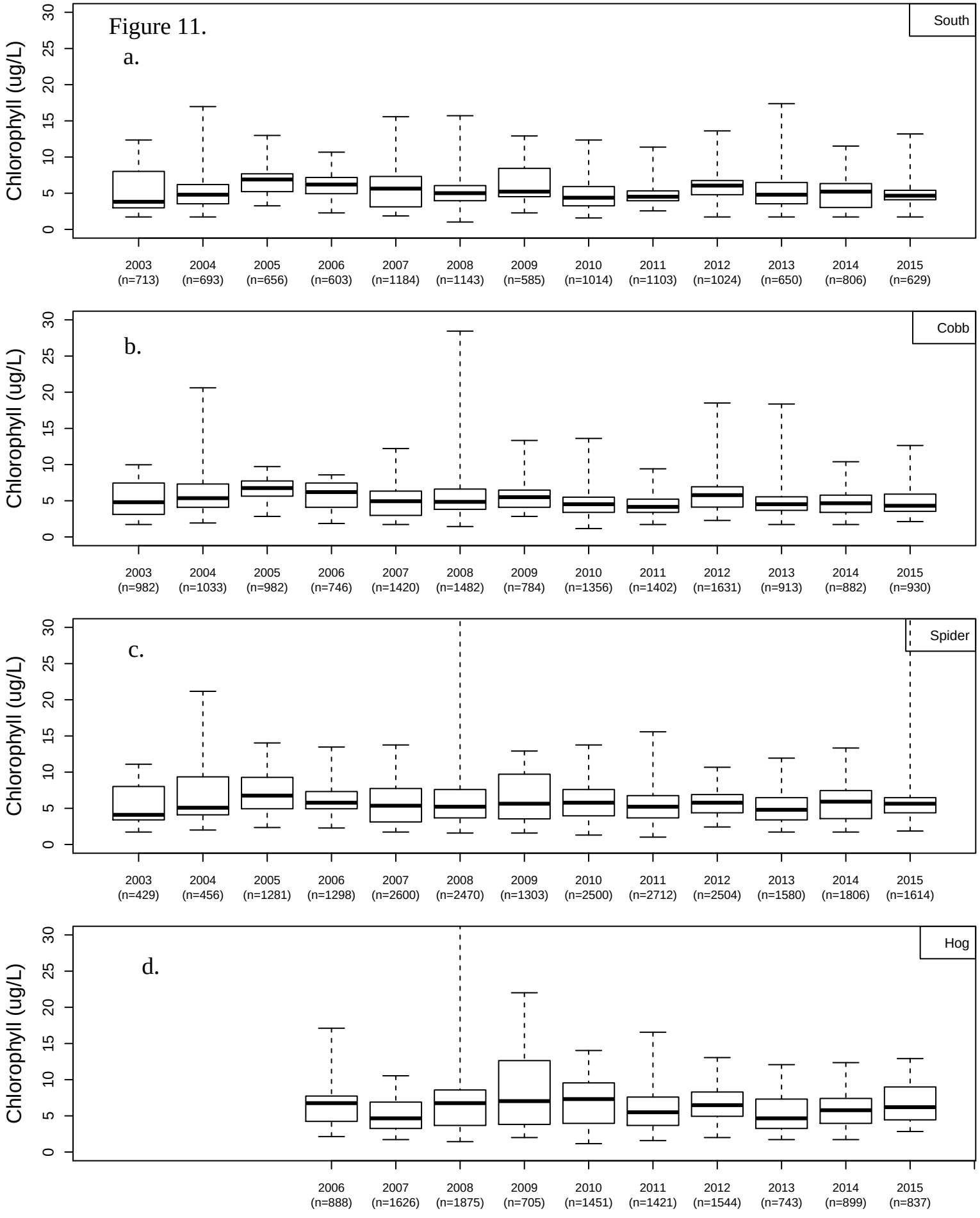


Figure 11.
a.
South
Chlorophyll (ug/L)
0
5
10
15
20
25
30
2003 (n=713)
2004 (n=693)
2005 (n=656)
2006 (n=603)
2007 (n=1184)
2008 (n=1143)
2009 (n=585)
2010 (n=1014)
2011 (n=1103)
2012 (n=1024)
2013 (n=650)
2014 (n=806)
2015 (n=629)
b.
Cobb
2003 (n=982)
2004 (n=1033)
2005 (n=982)
2006 (n=746)
2007 (n=1420)
2008 (n=1482)
2009 (n=784)
2010 (n=1356)
2011 (n=1402)
2012 (n=1631)
2013 (n=913)
2014 (n=882)
2015 (n=930)
c.
Spider
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)
2015 (n=1614)
d.
Hog
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)
2015 (n=837)

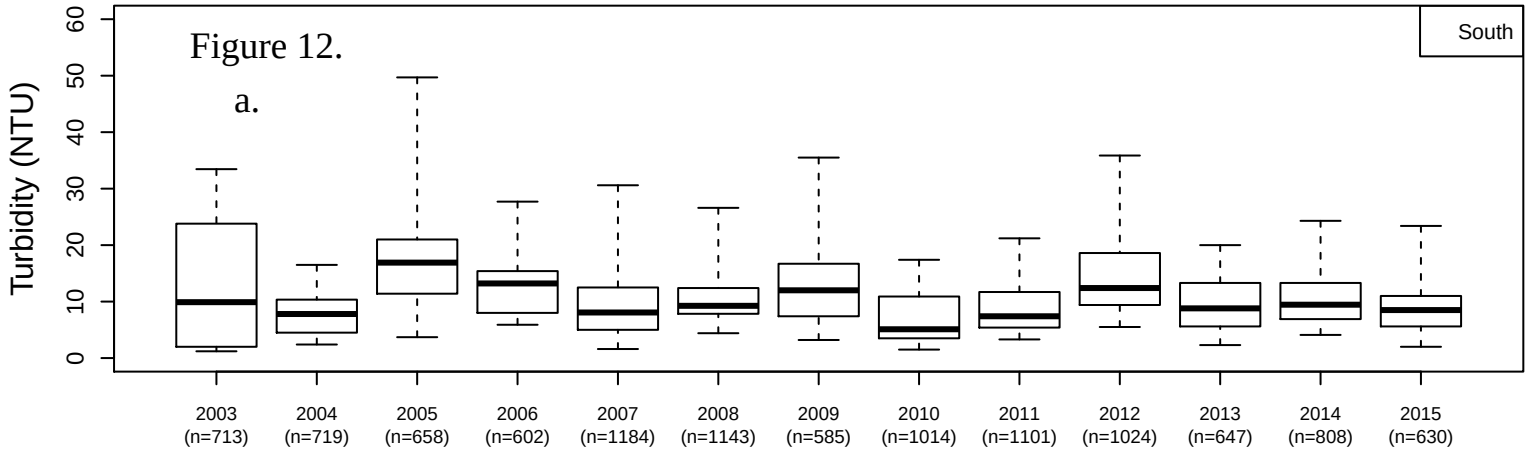
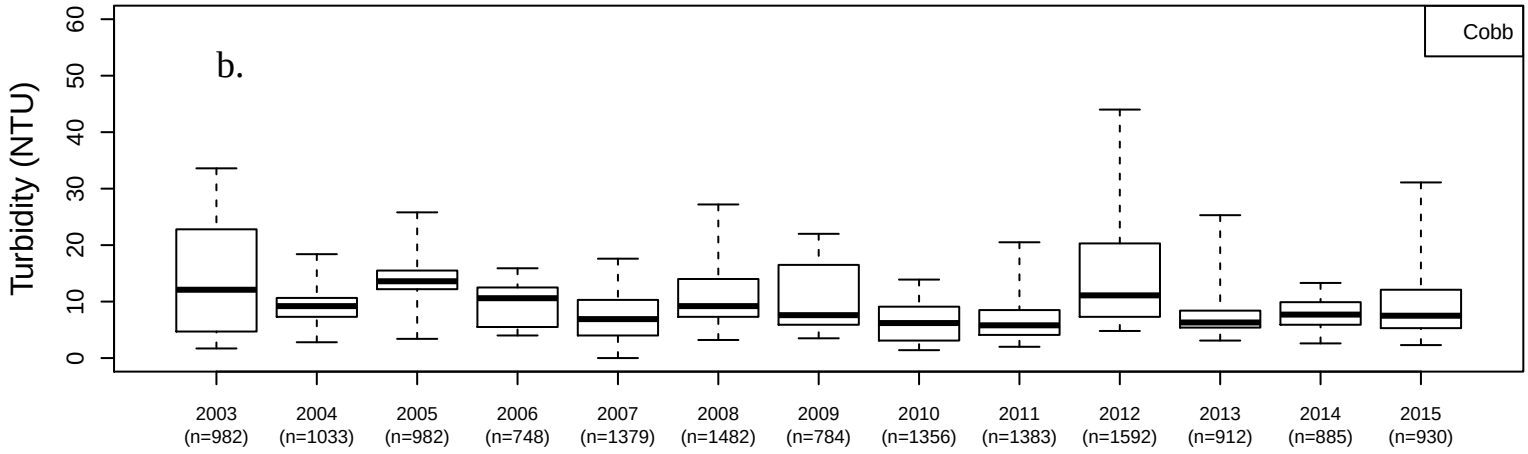
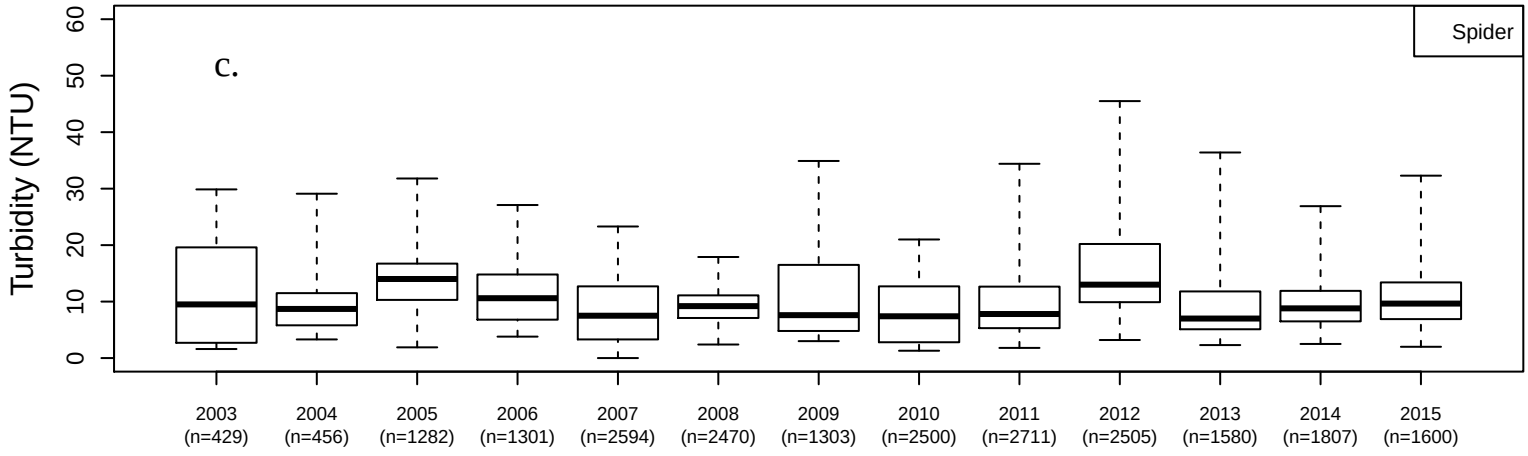


Figure 12.
a.
South
Turbidity (NTU)
0
10
20
30
40
50
60
2003 (n=713)
2004 (n=719)
2005 (n=658)
2006 (n=602)
2007 (n=1184)
2008 (n=1143)
2009 (n=585)
2010 (n=1014)
2011 (n=1101)
2012 (n=1024)
2013 (n=647)
2014 (n=808)
2015 (n=630)


b.
Cobb
Turbidity (NTU)
0
10
20
30
40
50
60
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)
2015 (n=930)


c.
Spider
Turbidity (NTU)
0
10
20
30
40
50
60
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)
2015 (n=1600)

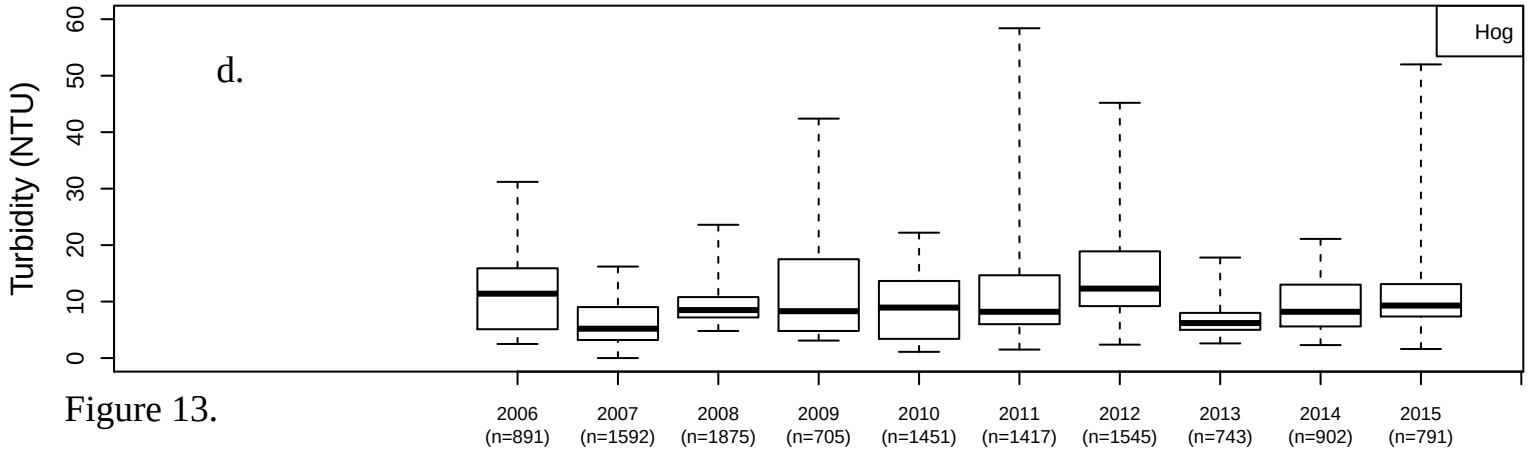

d.
Hog
Turbidity (NTU)
0
10
20
30
40
50
60
2006 (n=891)
2007 (n=1592)
2008 (n=1875)
2009 (n=705)
2010 (n=1451)
2011 (n=1417)
2012 (n=1545)
2013 (n=743)
2014 (n=902)
2015 (n=791)

Figure 13.

Figure 13a.

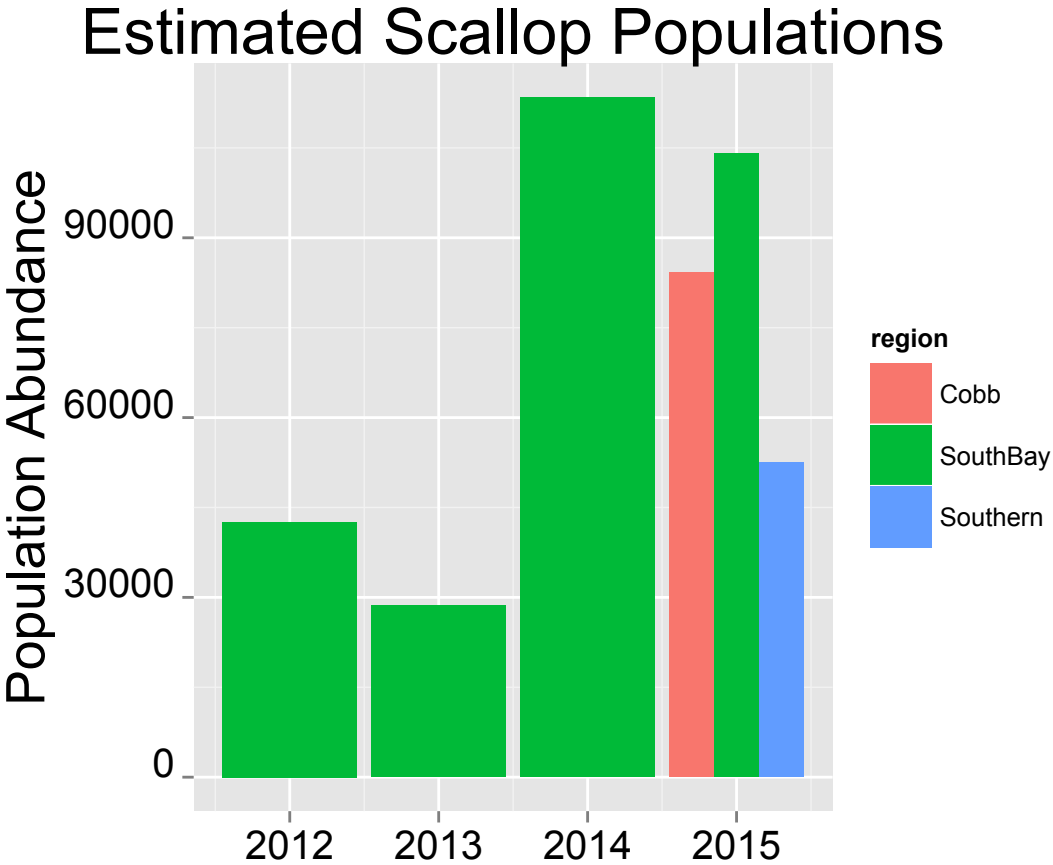
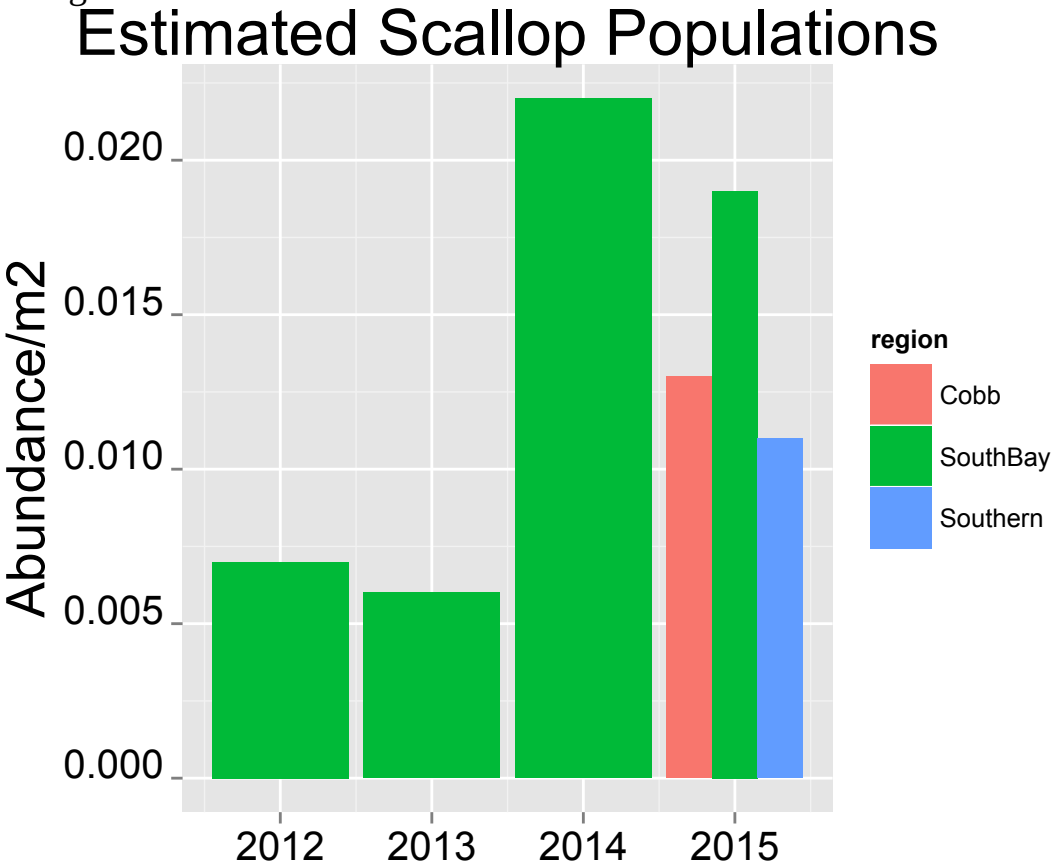

Estimated Scallop Populations
Population Abundance
90000
60000
30000
0
2012
2013
2014
2015
region
Cobb
SouthBay
Southern

Figure 13b.


Estimated Scallop Populations
Abundance/m2
0.020
0.015
0.010
0.005
0.000
2012
2013
2014
2015
region
Cobb
SouthBay
Southern