Final Report

To

Virginia Coastal Zone Management Program
and
National Oceanic and Atmospheric Administration

By

The Virginia Institute of Marine Science
College of William and Mary

March 16, 2009

Restoration of Seagrasses in Virginia Seaside Bays
Year 6 (Oct. 1, 2007, to Dec. 31, 2008) and Summary
FY 2007 Task 10.01

By

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This report was funded by the Virginia Coastal Zone Management Program at the Department of Environmental Quality through Grant #NA07NOS4190178 Task 10.01 of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, under the Coastal Zone Management Act of 1972, as amended.

The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Department of Commerce, NOAA, or any of its subagencies.

INTRODUCTION

The system of barrier islands, bays, and salt marshes along the Atlantic coast of Virginia's portion of the Delmarva Peninsula represent some of the most natural, unspoiled coastal habitat along the U.S. East Coast. Historically, finfish and shellfish resources in this region supported large fisheries. However, during the 1930s, this region underwent a dramatic ecological shift, and seafood harvests declined dramatically.

Seagrasses, primarily eelgrass, Zostera marina, were once very abundant in these bays, covering most of the shallow, sub-tidal sub-aqueous bottom. In the 1930s eelgrass underwent a massive decline attributed to a wasting disease pathogen, Labyrinthula sp. The decline was pandemic, affecting not only populations in the seaside bays but also populations on both sides of the Atlantic. In August 1933, this region was affected by one of the most destructive hurricanes to influence the area in the twentieth century, contributing to the decimation of seagrasses in the bays. Natural recovery of seagrasses had been limited primarily to Chincoteague, Sinepuxent, Isle of Wight and Assawoman bays. No recovery was documented in Virginia's more southern seaside bays during this same period, which was attributed to a limited supply of propagules and short dispersal capabilities.

One of the most notable consequences of the loss of seagrass habitat in the seaside bays was the immediate collapse of a previously productive commercial bay scallop fishery, which is dependent on seagrasses as primary habitat. Almost certainly this loss of seagrass habitat resulted in declines in production of other commercially and ecologically important species, but little documentation of these impacts is available

We initiated a seagrass restoration program in the seaside bays, with funding from the Virginia CZM Program, in Magothy Bay in 1997, and South Bay in 1998, using test plots of adult transplants. The success of the test plots and the discovery of several natural patches in South Bay led us to conduct seed addition experiments there in 1999 and 2000 (with funding from Virginia CZM's Oyster heritage Program). The success of the seed experiments and the sustained growth of previous transplants in South Bay led the Virginia Marine Resources Commission (VMRC) to designate a 400 acre area of subtidal habitat in South Bay to be set aside for seagrass restoration. In the fall of 2001 and 2002 through Virginia CZM's Seaside Heritage Program, we broadcast 3.8 and 1.8 million seeds into 24-one acre parcels in the 400-acre set aside area each year. In addition we broadcast 600,000 seeds into 4 one-acre parcels in lower Cobb Island Bay and 600,000 seeds into 6 one-acre plots in Magothy Bay in 2001. The continued success of this effort led to expanded efforts as part of the Seaside Heritage Program from 2002 through 2008.

A notable milestone of the seaside restoration effort in 2005 and 2006 was the Virginia Marine Resources Commission's establishment, at our request, of a 500 acre set-aside near High Shoal Marsh in Hog Island Bay for 5 years (Fig. 1) and the continuance of our set-aside in South Bay. In addition we requested and were granted an expansion of 366.36 acres, giving us a total of 727.85 acres as set-aside in South Bay to allow the continuation of successful seagrass restoration efforts.

The seagrass restoration program had six tasks as part of its annual program: 1. Use test plots in prospective restoration areas to assess site suitability for large scale plantings; 2. Collect seeds for large scale restoration efforts; 3. Initiate large scale restoration of these bays using seeds; 4. Monitor the success and subsequent spread of seeded plots; 5. Use remote sensing to map the seagrass beds; and 6. Monitor water quality with a continuously recording sensor at a selected site as well as with periodic spatially intensive water quality mapping.

Here we report activities conducted in the last year of the SHP (2008) and the highlights of the overall successes of the entire program.

Task 1 – Use test plots to identify future areas of large scale restoration.

We did not establish test plots in the fall of 2008 as this was the last year of funding from the Virginia CZM Program for the Seaside Heritage Program. However, test plots of adult plants and seedlings were successfully used in each of the first four years of the program to identify potential areas in Cobb, Spider Crab and Hog Island bays (Fig. 1). The success of test plots in each of these bays after one full year of growth as reported in our earlier final reports subsequently led to large scale restoration in succeeding years. The only area we did not have successful seed plots was in an area just southwest of Hog Island Bay in a large shoal area that was part of the Baylor Public Grounds. These plots were planted in 2004 and all died in the summer of 2005. This was the summer when eelgrass died back in the Chesapeake Bay but where only minor reductions occurred in established beds in the coastal bays. It is possible that these test plantings were more susceptible than established beds in the seaside bays, but due to the failure of these plots, we excluded this area from large-scale restoration efforts.

Task 2 and 3 – Collect seeds for large scale restoration and embark on large scale restoration.

In 2008, we harvested approximately 3.3 million seeds. Seed collection in 2008 was quite notable in that all our seed harvesting occurred in the South Bay restoration area where 10 years earlier there was no eelgrass. In addition, we teamed with The Nature Conservancy to use primarily volunteers to harvest eelgrass flowering shoots. Volunteer contributions were extraordinary. A total of 85 volunteers assisted in the seed collection as we averaged 10 volunteers a day for roughly two weeks. This effort continues in 2009: http://www.deq.virginia.gov/coastal/vshp/event.html

In 2008 we established six one acres sites in Hog Island Bay and four one-half acre sites in Spider Crab Bay at a rate of 100,000 seeds per acre. Fig. 2 shows the position of the Hog Island Bay plots in relation to the 2006 and 2007 plots.

In summary, over 26 million seeds have been broadcast in 207 acres since we initiated our work with CZM funds in 1998 (Fig. 3).

Task 4 and 5 – Monitor success of seeded plots and use remote sensing to map beds.

Assessments of the seeded plots in all the four bays was facilitated by our aerial photographic overflights. Mapping of the SAV in these bays revealed that by 2007,

almost 1400 acres had seagrass (Fig. 3). We also included an estimate of bottom cover (Fig. 3) the estimated area of eelgrass canopy cover calculated from the weighted sum of areas in four cover classes assigned during mapping. Fig. 4 shows a collage of four aerial photographs revealing the spread of eelgrass between 2002 and 2008 showing the dense coverage of eelgrass by 2008 from the seeded plots in 2001 and 2002. Figs. 5 and 6 show the restoration sites in Cobb and Spider Crab bays. Eelgrass growth from seeded plots has occurred, and like South Bay, is remarkable in its persistence. We anticipate continued growth and spread of eelgrass in subsequent years in these two bays, as well as Hog Island Bay, which is the bay with the most recent seeding. That spread can be seen in the Cobb Bay figure by observing the dark areas between the 2001 1-acre square plots and 2003 half-acre ring plots.

Hog Island Bay plots seeded in 2006 and 2007 were assessed for plant abundance in 2008 (Fig. 7). Eelgrass persisted in these plots but shoot density was quite variable for both plot densities.

Task 6 – Water quality measurements using fixed station continuous monitors and surface mapping of water quality with dataflow

During 2008, continuous underway sampling (DATAFLOW) and fixed station water quality measurements were made in the Virginia Coastal Bays restoration area in a manner similar to previous monitoring years. The DATAFLOW cruise track conducted in 2008 (Figure 1) traversed transplant restoration areas in South Bay, Cobb Bay, Spider Crab Bay, and Hog Island Bay. Cruises were conducted monthly throughout the seagrass growing season on March 27, April 30, May 29, June 25, July 21, August 22, September 18, October 21 and November 20. A YSI 6600 was deployed at a fixed monitoring station at the Wreck Island restoration site in South Bay at bi-monthly intervals throughout the growing season over the following range of dates; March 29 to April 26, June 13 to July 29, August 13 to September 314 and October 10 to November 8.

The DATAFLOW underway sampler recorded in vivo measurements of surface water quality taken at 2-3 second intervals (0.25 m depth; approximately every 50 m) along each cruise track. Measurements included turbidity (NTU), chlorophyll fluorescence, temperature, salinity, pH, dissolved oxygen, GPS location and depth using a YSI 6600 EDS sensor array (Yellow Springs Instruments, Inc.). In addition to the continuous underway sensor measurements, eight calibration and verification stations were sampled at discrete stations along each cruise track for total suspended solids, light attenuation profiles, secchi disk measurements, extracted pigment chlorophyll and dissolved oxygen via Winkler Titration. Concurrent with every other cruise (bi-monthly), two week deployments of a YSI 6600 EDS sensor array identical to that used in the DATAFLOW sampler were undertaken at the South Bay - Wreck Island restoration site. Here, water quality was measured at 15-minute intervals throughout each 2-week deployment. These deployments bracketed, by approximately one week, each DATAFLOW water quality, monitoring cruise.

Figures 8a–8d present the continuous underway DATAFLOW cruise tracks of water quality measurements for turbidity, chlorophyll, and salinity for the four monthly

cruises that were paired with fixed monitoring station deployments during the SAV growing season in 2008. Results of the other cruises showed similar trends.

Salinities again were found to be very consistent throughout the Seaside Bays area although salinities increased seasonally from 31.5 in the spring to 33 in August before decreasing slightly by October. This summer increase was higher than seen in earlier years but these slight differences are not thought to have any significant effects on eelgrass growth and survival.

Turbidity levels varied throughout the region with highest levels often observed in the western Seaside Bays region near Oyster, VA, especially during the summer. Turbidity levels were usually lower over the four restoration study areas. Most of these areas were associated with high turbidities within or near marsh creeks connecting the individual bays. We have determined that turbidity levels of 10 NTU or less in the Virginia Seaside Bays are equivalent to a light attenuation coefficient (K_d) of $\leq 1.5\ m^{-1}$. In the Chesapeake Bay these light attenuation levels have been associated with shallow water areas where SAV have been found growing to depths of 1m at MLW. For most of the restoration areas turbidity levels in 2008 were at or below these levels.

Low water column chlorophyll levels were again typical of both the transplant sites and the seaside bay regions throughout 2008, with concentration typically below 5 ug/l. In the Chesapeake Bay chlorophyll levels of 15 µg/l or greater have been associated with SAV habitats that are under stress or in decline. As with salinity, chlorophyll levels appear consistent among the sites. A few high spikes over short distances may have been due to small patches of phytoplankton or re-suspension of benthic microalgae

Continuous monitoring (CMON) records of turbidity, chlorophyll, salinity and depth for the four, bi-monthly fixed monitoring station deployments are presented in Figures 9a–9d. Tides ranged from 1 – 2 meters. Salinities showed similar seasonal trends to the Dataflow cruises with highest levels in August. Periodic high levels of turbidity due to re-suspension during storm or wind events were evident for a few days in April, August and October and November.

Tidal cycles and waves appear to play important roles in affecting both turbidity and the phytoplankton component of the turbidity in the South Bay restoration area again in 2008. There was a distinct tidal periodicity to the chlorophyll and turbidity levels with higher concentrations evident during incoming high tides. On most low tides both turbidity and phytoplankton levels dropped (Figures 9a–9d), suggesting that a rapid settling of particles and clearing of the water was occurring. For the most part, tides had little effect on salinity levels, although occasionally salinity dropped with incoming tides in August-September. Water temperatures did not exceed 30 C during the sampling periods and decreased 1-2 C with every high tide (data not shown). This influx of cooler coastal water is in contrast to eelgrass beds in the Chesapeake Bay where water temperatures may exceed 30 C during the summer, resulting in heat stress and other factors that negatively affect eelgrass survival.

Table 1 summarizes the turbidity and chlorophyll constituents of water quality at South Bay during the four bi-monthly sampling periods in 2008 as well as the three, intensive sampling periods for 2005 through 2007. Mean values highlighted in red indicate they are above water quality habitat thresholds of 15 ug/l chlorophyll and 10 NTU. Extremely high, single point spikes that may have been due to sensor optical fouling or blockage were removed for these summaries. Turbidity levels were generally below the 10 NTU threshold in April, June and October and overall were lower than previous years at this site. This decrease may reflect increasing abundance of eelgrass due to plant restoration at the site. High maximum levels of turbidity were likely due to re-suspended of benthic sediments. Typically as eelgrass abundance exceeds 25-50% cover of the bottom re-suspension is decreased and particle settlement is enhanced (Moore 2004). The continuous monitoring data indicate that there were also distinct effects of tidal height and stage on turbidity. Flood tidal currents may be increasing sediment concentrations and allowing broader wave intrusion onto the flat. Additionally the effects of the plant canopy on wave effects are enhanced at lower tidal stages.

Data previous to 2008 has demonstrated that the relatively cool water temperatures experienced by seagrass restoration areas in the seaside bays may have important implications for successful eelgrass re-colonization compared to areas historically vegetated with eelgrass in the lower Chesapeake Bay. In the summer of 2005 a broad, significant dieback of eelgrass was observed throughout the lower Chesapeake Bay (Orth et al. 2007). In contrast, there was significant expansion of eelgrass transplants in the seaside bays transplant sites (Orth et al. submitted). Moore and Jarvis (2008) have demonstrated that the decline of eelgrass in the lower bay was associated with unusually high water temperatures during periods in the summer of 2005 compared to 2004 and 2006. High water temperatures (>28º) can stress eelgrass in a variety of ways, but especially by increasing respiratory requirements of the plants and consequently the compensating light levels (I_c) needed for sustained growth and survival (Moore 2004). A difference of only a few degrees for only a small percent of the time can make the difference between survival and defoliation and death. Figure 10 provides a comparison of continuous monitoring data for the periods of deployment at the South Bay restoration areas with two lower Chesapeake Bay sites (Goodwin Island and Claybank) historically vegetated with eelgrass in the York River. Goodwin Island is located near the mouth of the York River and here the existing eelgrass beds had near complete defoliation by September 2005 (Moore and Jarvis 2008). Claybank is an upriver area where eelgrass has historically grown, but restoration efforts have had little success over the last 20 years. Using an established relationship between water temperatures and compensating light requirements (I_c) developed using field studies of eelgrass bed metabolism in the lower Chesapeake Bay region (Moore 2004), the light requirements of eelgrass were computed for each 15-minute sampling interval at each of the three sites. In addition, the underwater light available for the eelgrass (I_z) was determined using simultaneous measurements of water column turbidity and water depth. Figure 10 shows the percent of time that the light availability (I_z) was less than or equal to the light needed for growth and survival (I_c) for each of the two week study periods throughout 2005. The overall pattern for all sites was for a decrease in the percent of time $I_c \geq I_z$ during the summer as increasing water temperatures increased the effective compensating light levels. Among

the sites, Claybank which had the highest turbidities, I_c was greater than or equal to I_z for only a few percent of the time during the October 2005 sampling period. In contrast the South Bay restoration site had by far the highest proportion of time that $I_c \geq I_z$ throughout the year, especially during the critical summer period. Turbidities at South Bay were actually slightly higher than the Goodwin Island site, primarily due to sediment re-suspension, but not as high as Claybank. Water temperatures were, however, significantly cooler due to the influence of the cool ocean water. This suggests that the successful transplant areas in the coastal bays are being favorably influenced by their proximity to the inlets, and suggests that western areas in the coastal bays further removed from regular tidal replenishment by ocean water may not be as suitable for seagrass growth, especially if turbidities there are higher there as suggested by the Dataflow mapping surveys.

Conclusion

In conclusion, the success of the seagrass restoration program in the Virginia Seaside Bays is remarkable in size and magnitude of the restoration effort over the past six years. The spread of eelgrass, especially in South Bay, occurred at rates that far exceeded expectations. The expansion of eelgrass in each of the bays used as restoration sites, and where eelgrass has survived and expanded, stands in stark contrast to the patterns of eelgrass in Chesapeake and Chincoteague Bay (Fig. 11). Over the last decade, eelgrass populations in both these bays have declined and are now at abundance levels similar to levels first mapped. These changes have been attributed to declining water quality in the respective bays as well as environmental conditions that have stressed the plants, e.g. the very hot summer of 2005. The unique perspective we have gained by comparing and contrasting eelgrass populations and the environmental conditions occurring in the lower Seaside Bays has revealed interesting differences that influence the ultimate survival of the plant. With water quality declining in Chesapeake Bay and Chincoteague Bay, the Virginia Seaside Bays (south of Chincoteague) may provide refugia for eelgrass populations.

References

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Moore, K. A. and J. C. Jarvis. 2008. Environmental factors affecting recent summertime eelgrass diebacks in the Lower Chesapeake Bay: implications for long-term persistence. Journal of Coastal Research SI 55: 35-147.

Orth, R. J., D. J. Wilcox, L. S. Nagey, A. L. Owens, J. R. Whiting, and A. Kenne. 2007. 2006 Distribution of submerged aquatic vegetation in the Chesapeake Bay. VIMS Special Scientific Report Number 150. Final Report to NOAA, Washington, D.C. Grant No. NA06NMF4570118.

Orth, R. J., S. R. Marion, K. A. Moore, D. J. Wilcox. Submitted. Eelgrass (*Zostera marina* L.) in the Chesapeake Bay region of Mid-Atlantic Coast of the USA: Challenges in Conservation and Restoration

Table 1. Mean, minimum and maximum YSI 6600 turbidity and chlorophyll levels for the South Bay restoration study site during continuous monitoring deployment periods. Red indicates that the mean levels were above Chesapeake Bay derived eelgrass habitat requirements.

Deployment Dates	Turbidity			Chlorophyll		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
May 19-June 4, 2005	13.3	4.0	75.1	3.5	0.3	23.8
July 20-Aug 4, 2005	16.3	4.2	104.6	4.5	0.9	61.0
September 19-28, 2005	18.1	5.1	147.4	2.9	0.9	9.9
April 10-April 25, 2006	7.0	1.8	28.3	1.2	0.0	8.3
June 16-July 10, 2006	12.2	2.1	286.3	6.0	0.9	124.2
Aug 19-Sept 24, 2006	26.8	3.5	193.1	3.4	1.1	24.5
Oct 10-Nov 3, 2006	22.7	3.6	219.7	3.7	0.9	9.5
March 29-April 26, 2007	13.84	1.4	144.3	1.9	0.0	19.5
June 13-June 29, 2007	7.30	2.0	32.4	9.1	1.3	255.8
Aug 13-Aug 31, 2007	6.67	2.0	18.9	3.5	0.8	17.0
Oct 10-Nov 8, 2007	22.99	3.4	235.9	5.1	1.1	46.8
April 18-May 7, 2008	7.6	1.2	41.9	1.6	0.1	4.1
June 22-July 3, 2008	5.5	0.9	40.9	3.1	1.4	13.8
Aug 21-Sept 3, 2008	10.7	1.8	54.8	9.3	0.6	24.1
Oct 9-18, 2008	8.5	2.8	51	3.6	0.9	6.6

LIST OF FIGURES

Figure 1. Overview map of eelgrass restoration sites in the Virginia seaside bays.

Figure 2. Diagram of plots seeded in Hog Island Bay between 2006 and 2008. Natural recruitment of eelgrass (not derived from restoration efforts in Hog Island Bay, but possibly established from floating reproductive shoots from restored plots in nearby bays), indicated in red outline, was discovered after distribution of 2006 plots.

Figure 3. Restoration trajectories from the Virginia Seaside Bays measured by three metrics: (1) Cumulative area seeded with eelgrass between 1998 and 2008; (2) Area mapped by an annual seagrass monitoring program each year through 2007, incorporating the entire polygon area surrounding restored plots; (3) Area of bottom cover through 2007, the estimated area of eelgrass canopy cover calculated from the weighted sum of areas in four cover classes assigned during mapping.

Figure 4. Sequence of aerial photographs of the South Bay restoration site for 2002-2008. One-acre plots distributed in 2001 are faintly visible as dark squares by 2002. Consolidation of plots is visible as a dark region along the east side of the bay in 2006. By 2008, the entire area between plots had consolidated into a largely continuous-cover meadow of over 750 acres.

Figure 5. Color aerial photograph of the Cobb Bay restoration site in 2008, showing regional spread of eelgrass from restored plots into the surrounding area.

Figure 6. Color aerial photographs of the Spider Crab Bay restoration site in 2008. (a) Early-stage development of 0.5-acre plots broadcast between 2004 and 2007, and test strips established by an experimental seed injection machine in 2006. (b) Regional spread of eelgrass nearby circular plots established in 2003.

Figure 7. Hog Island Bay restored plot performance measured as shoot density in summer 2008 for plots established in fall 2006 (n=12) or 2007 (n=14). Plots received either 50,000 or 100,000 seeds per acre. Data are combined for 0.5-acre and 1-acre plots, since plot size showed no impact on density. Shoot density measurements provided by Karen McGlathery (UVA LTER). Box plots indicate median, interquartile range, and range.

Figures 8a–8d: Continuous underway DATAFLOW cruise tracks of water quality measurements for turbidity, chlorophyll, and salinity for the four monthly cruises. The location of the fixed, continuous monitoring station (CMON) is highlighted with a circle, and the transplant study areas are highlighted with rectangles on each cruise figure. The restoration study sites identified in the figures are: South Bay-1, Cobb Bay-2, Spider Crab Bay– 3, Hog Island Bay- 4.

Figures 9a–9d: Continuous monitoring (CMON) records of turbidity, chlorophyll, salinity and depth for the four, bi-monthly fixed monitoring station deployments in South Bay.

Figure 10: Comparison of light availability (I_z) vs. light requirements (I_c) for Seaside Bays and Chesapeake Bay eelgrass sites during spring, summer and fall continuous monitoring deployment periods in 2005 and 2006.

Figure 11. Restored eelgrass trends in the Virginia seaside bays relative to trends for all SAV in Chesapeake Bay and Chincoteague Bay.

Figure 1

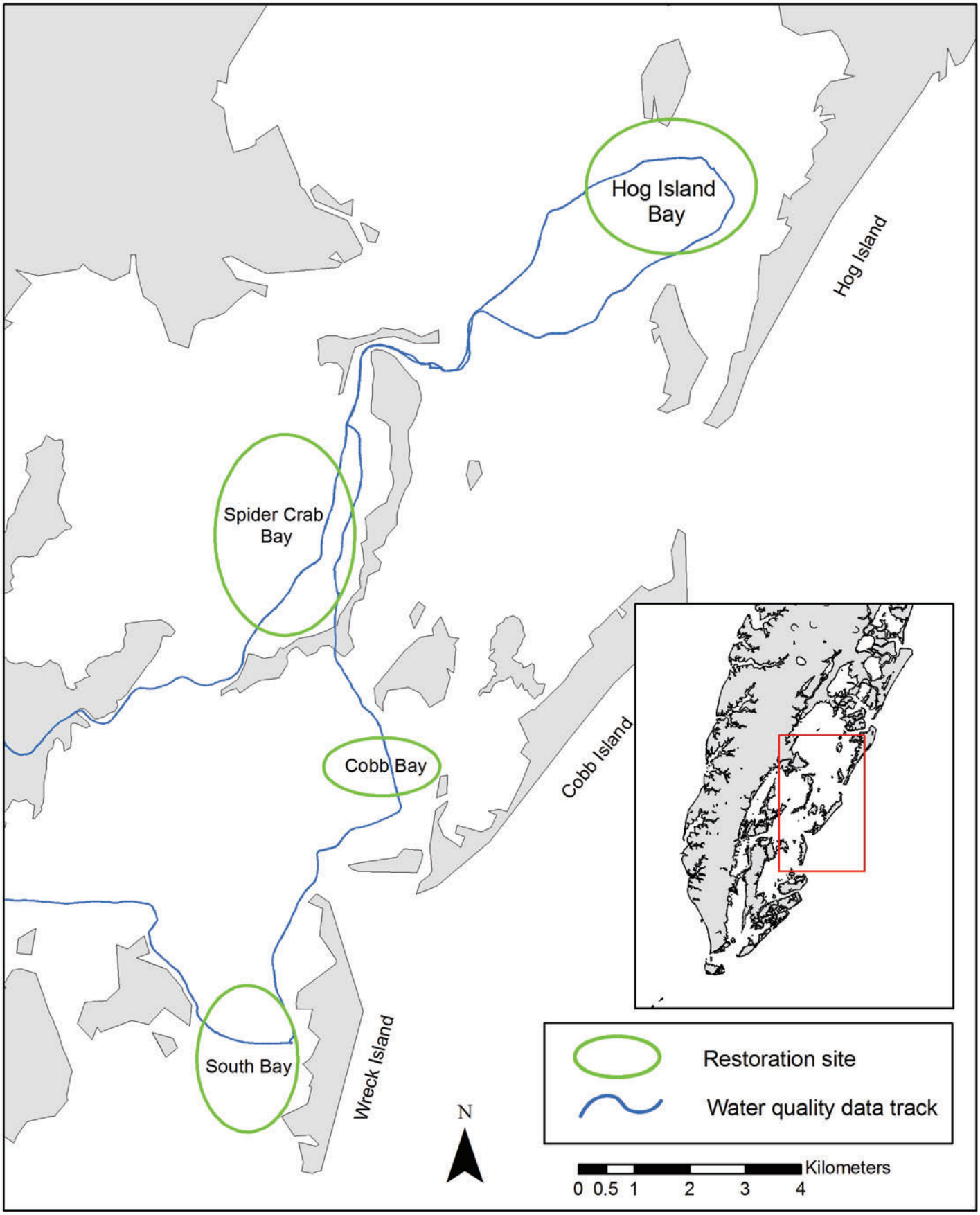

Hog Island Bay
Hog Island
Spider Crab Bay
Cobb Bay
Cobb Island
South Bay
Wreck Island
N
Restoration site
Water quality data track
Kilometers
0 0.5 1 2 3 4

Figure 2

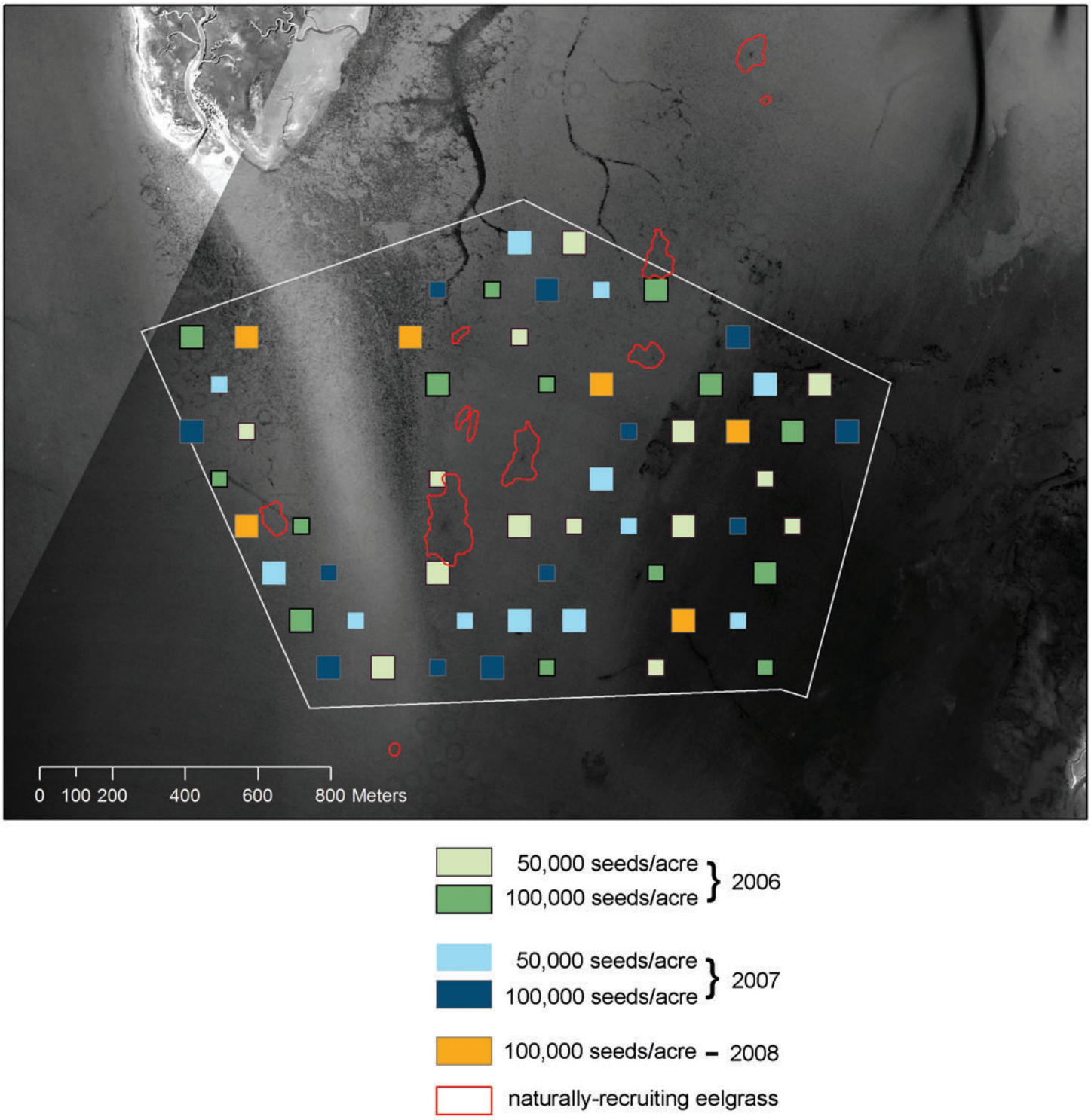

0 100 200 400 600 800 Meters
50,000 seeds/acre
100,000 seeds/acre
2006
50,000 seeds/acre
100,000 seeds/acre
2007
100,000 seeds/acre – 2008
naturally-recruiting eelgrass

Figure 3

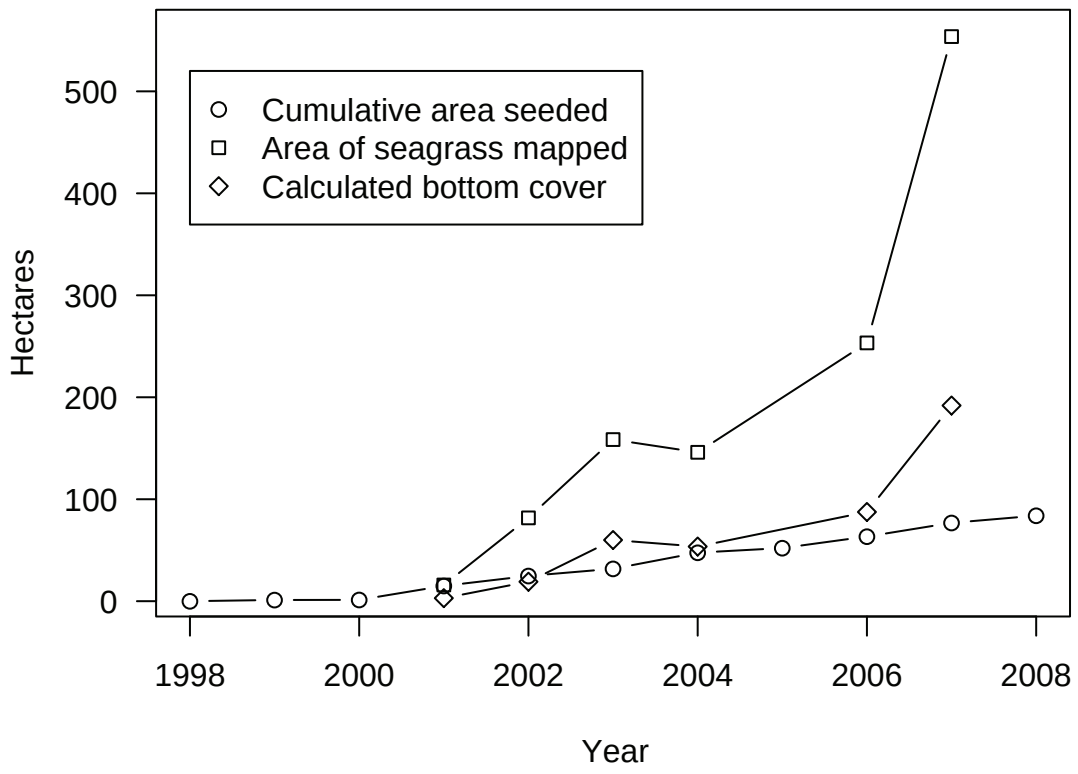

Cumulative area seeded
Area of seagrass mapped
Calculated bottom cover
Hectares
0
100
200
300
400
500
1998
2000
2002
2004
2006
2008
Year

Figure 4

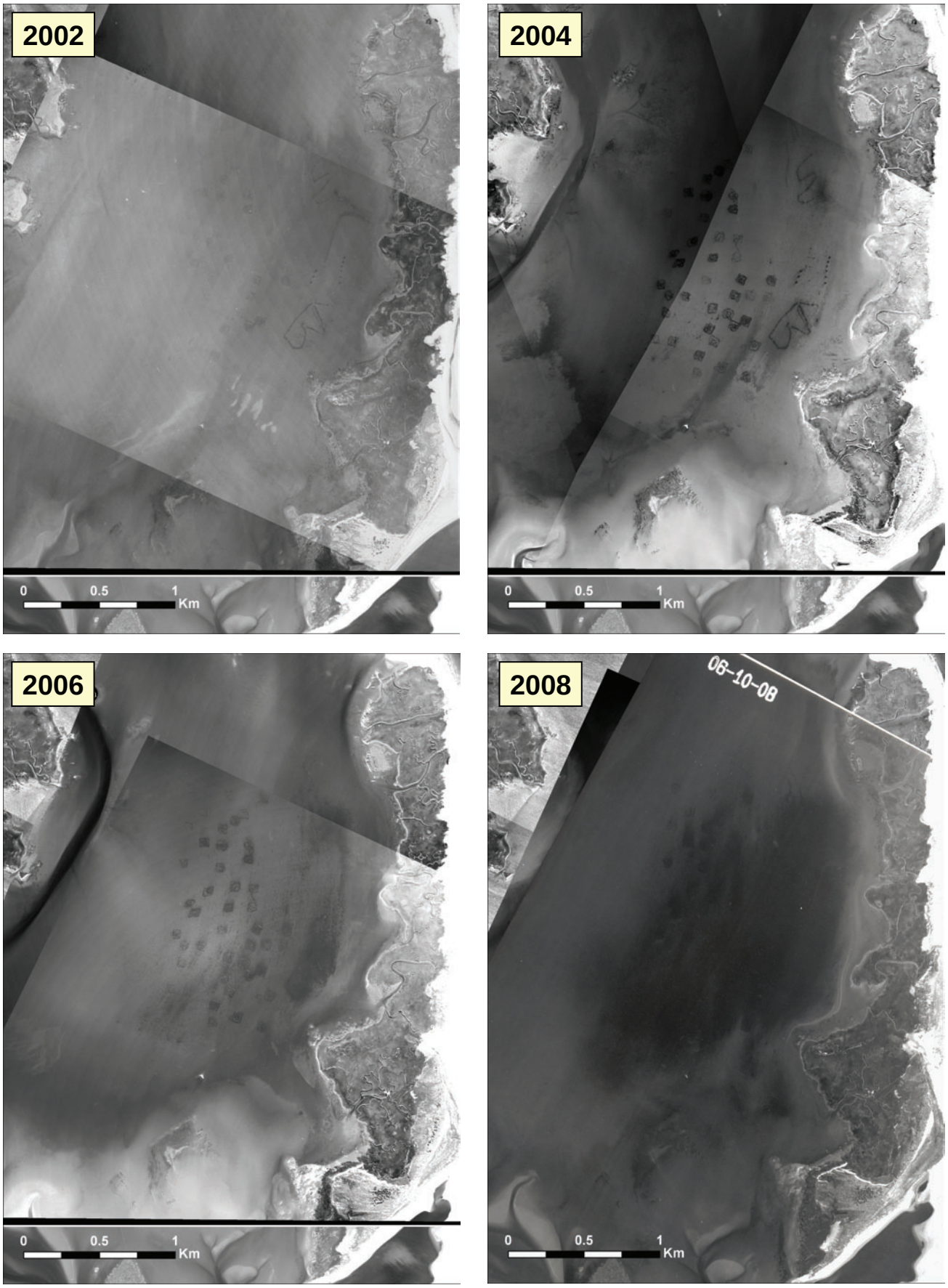


Figure 5

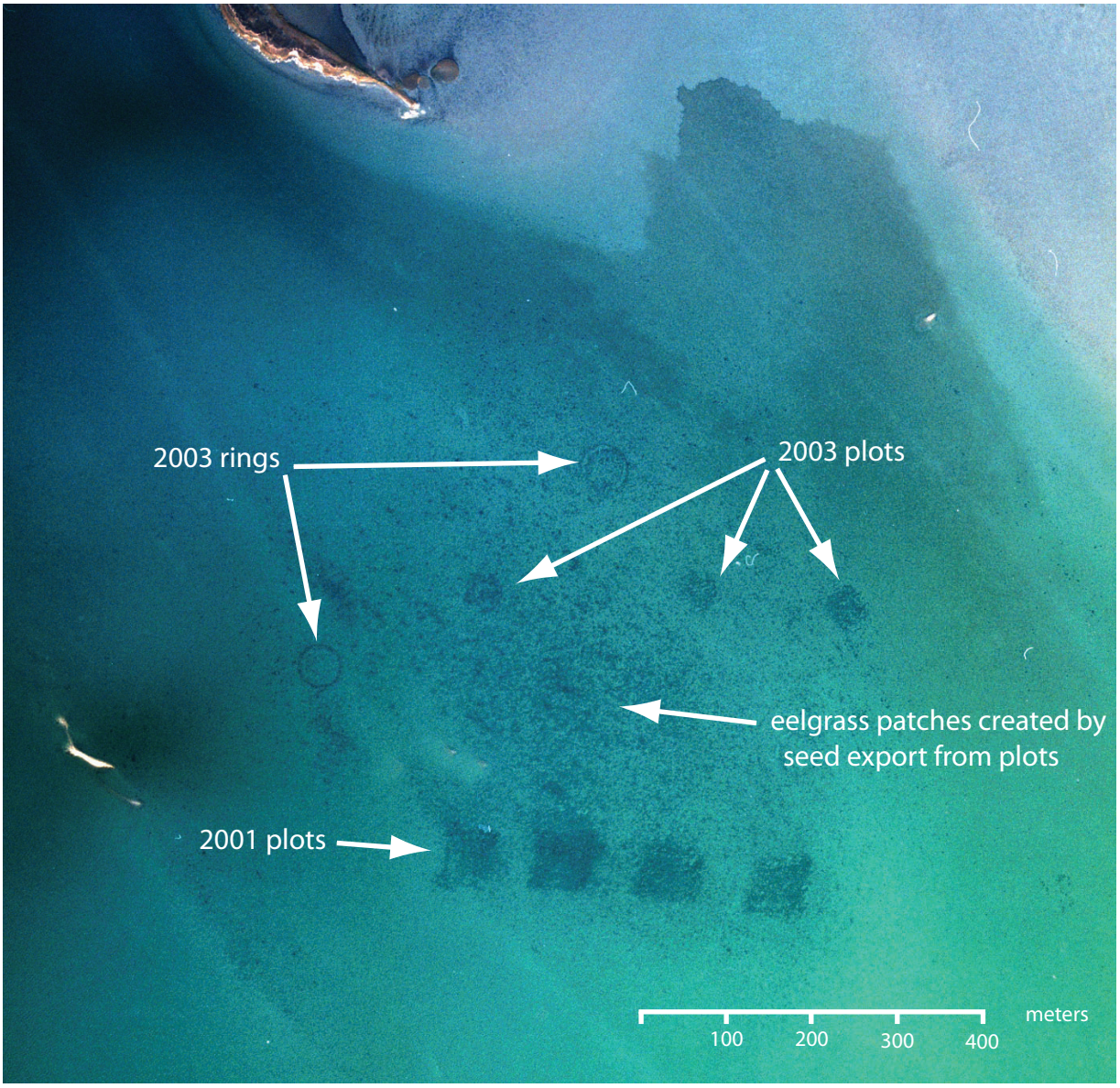
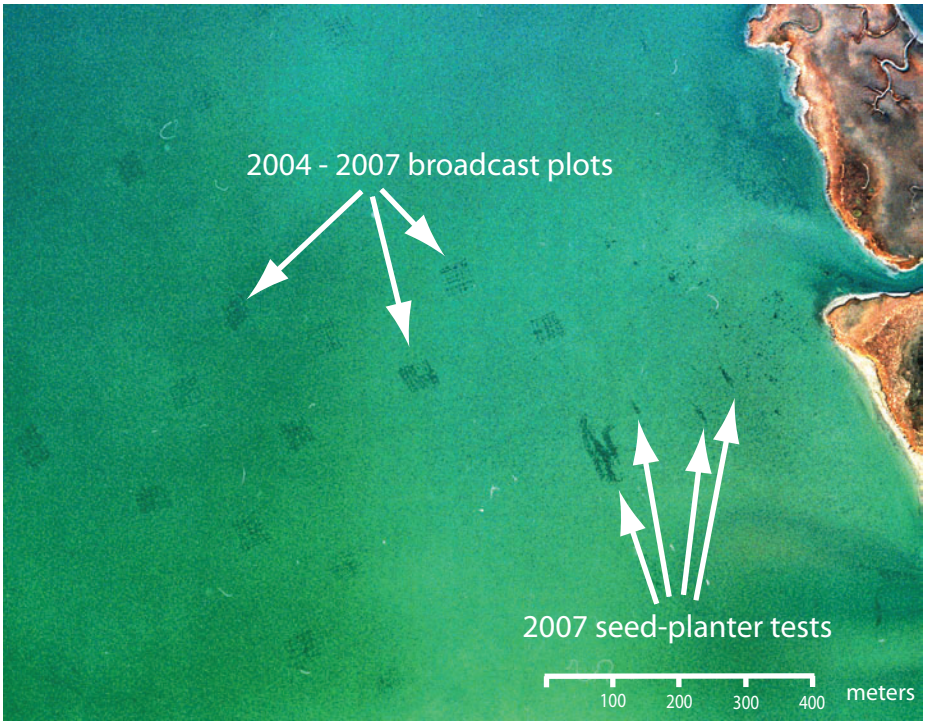

2003 rings
2003 plots
eelgrass patches created by
seed export from plots
2001 plots
meters
100
200
300
400

Figure 6

a)


2004 - 2007 broadcast plots
2007 seed-planter tests
100
200
300
400
meters

b)

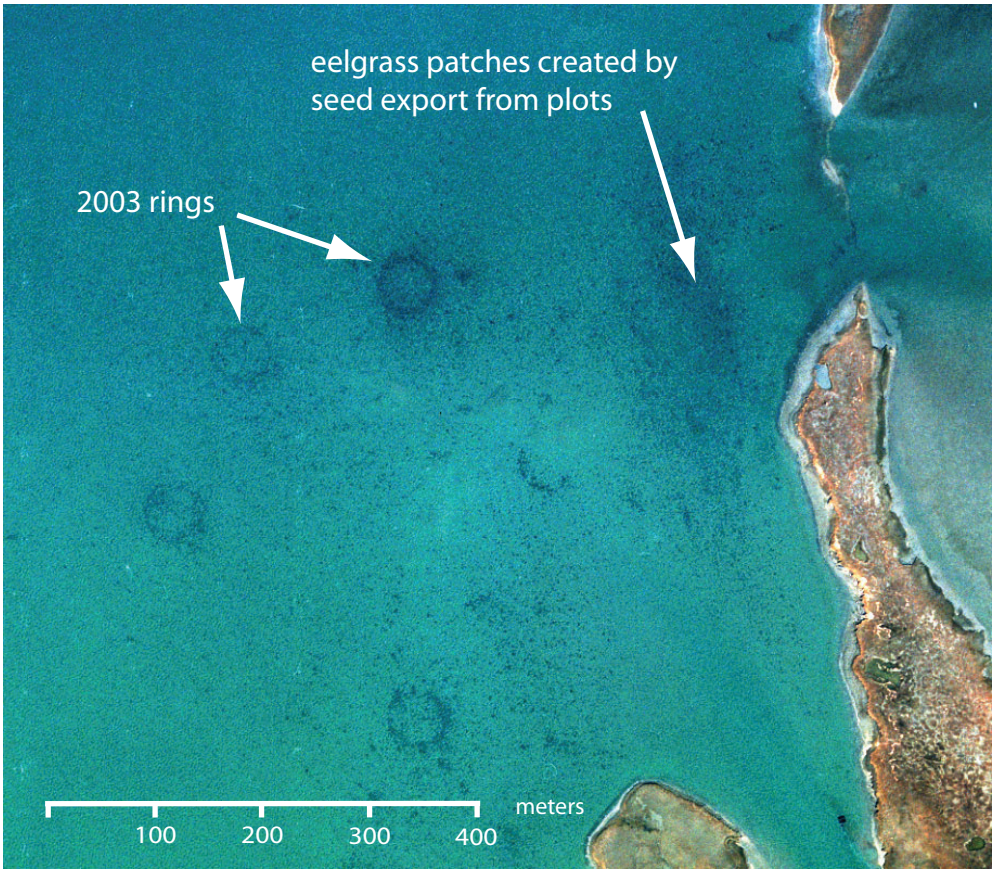

eelgrass patches created by
seed export from plots
2003 rings
100
200
300
400
meters

Figure 7

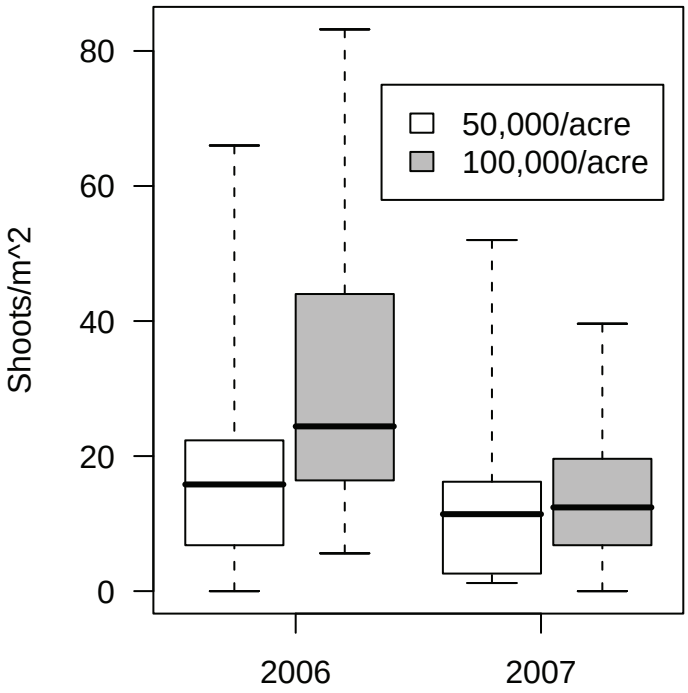


Figure 8a

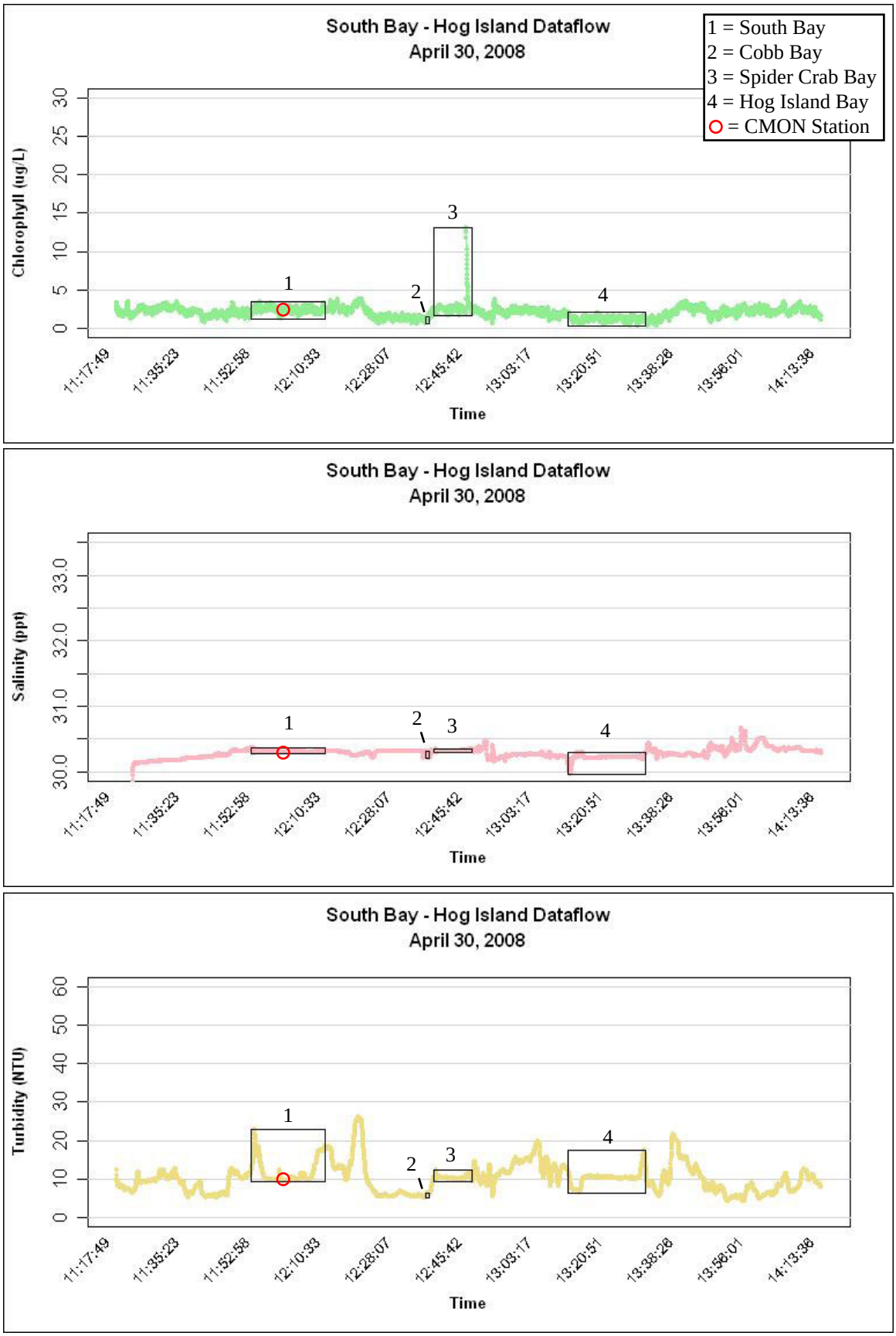

South Bay - Hog Island Dataflow
April 30, 2008
1 = South Bay
2 = Cobb Bay
3 = Spider Crab Bay
4 = Hog Island Bay
= CMON Station
Chlorophyll (ug/L)
0
5
10
15
20
25
30
1
2
3
4
11:17:49
11:35:23
11:52:58
12:10:33
12:28:07
12:45:42
13:03:17
13:20:51
13:38:26
13:56:01
14:13:38
Time
South Bay - Hog Island Dataflow
April 30, 2008
Salinity (ppt)
30.0
31.0
32.0
33.0
1
2
3
4
11:17:49
11:35:23
11:52:58
12:10:33
12:28:07
12:45:42
13:03:17
13:20:51
13:38:26
13:56:01
14:13:38
Time
South Bay - Hog Island Dataflow
April 30, 2008
Turbidity (NTU)
0
10
20
30
40
50
60
1
2
3
4
11:17:49
11:35:23
11:52:58
12:10:33
12:28:07
12:45:42
13:03:17
13:20:51
13:38:26
13:56:01
14:13:38
Time

Figure 8b

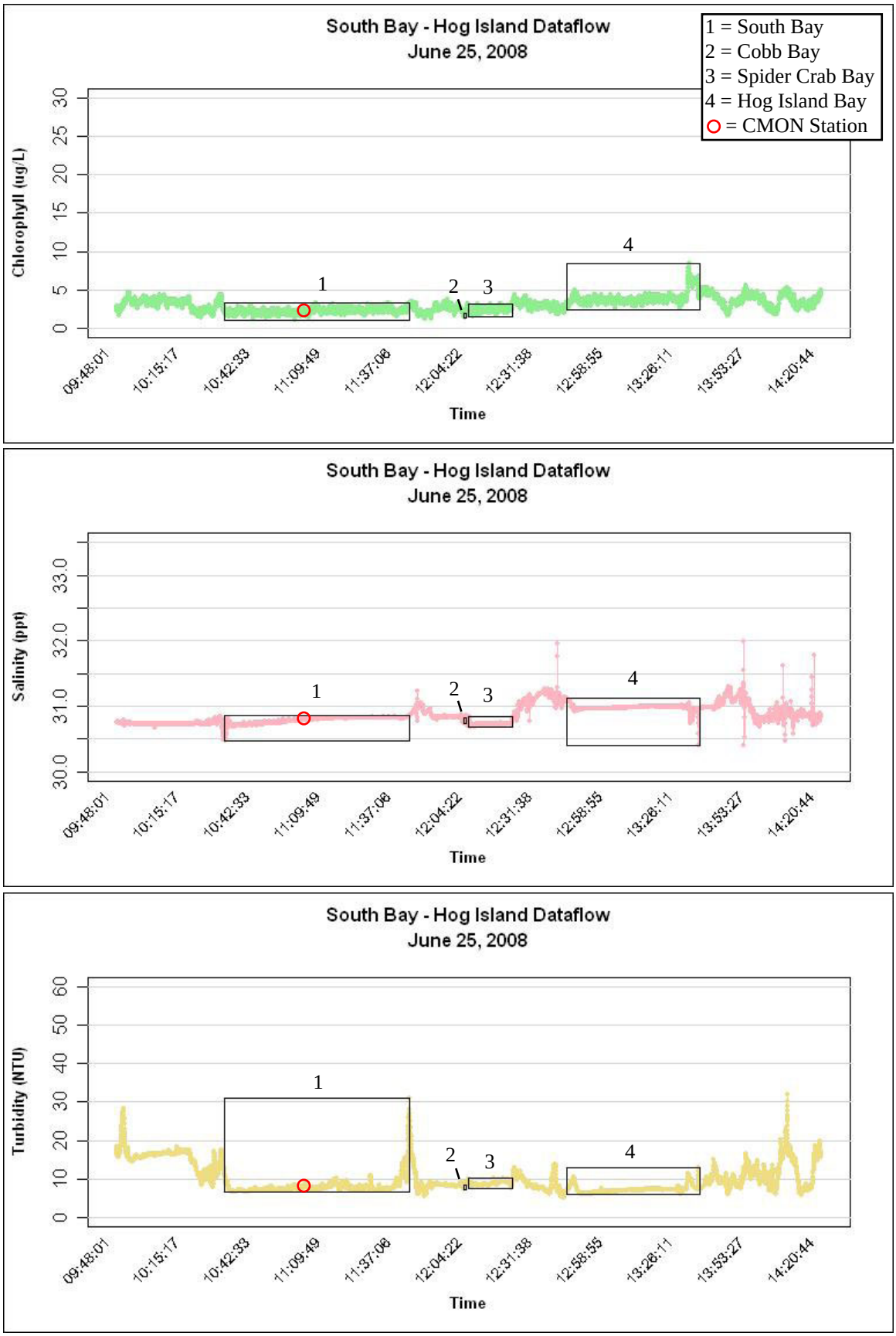

South Bay - Hog Island Dataflow
June 25, 2008
1 = South Bay
2 = Cobb Bay
3 = Spider Crab Bay
4 = Hog Island Bay
= CMON Station
Chlorophyll (ug/L)
0
5
10
15
20
25
30
1
2
3
4
09:48:01
10:15:17
10:42:33
11:09:49
11:37:06
12:04:22
12:31:38
12:58:55
13:26:11
13:53:27
14:20:44
Time
South Bay - Hog Island Dataflow
June 25, 2008
Salinity (ppt)
30.0
31.0
32.0
33.0
1
2
3
4
09:48:01
10:15:17
10:42:33
11:09:49
11:37:06
12:04:22
12:31:38
12:58:55
13:26:11
13:53:27
14:20:44
Time
South Bay - Hog Island Dataflow
June 25, 2008
Turbidity (NTU)
0
10
20
30
40
50
60
1
2
3
4
09:48:01
10:15:17
10:42:33
11:09:49
11:37:06
12:04:22
12:31:38
12:58:55
13:26:11
13:53:27
14:20:44
Time

Figure 8c

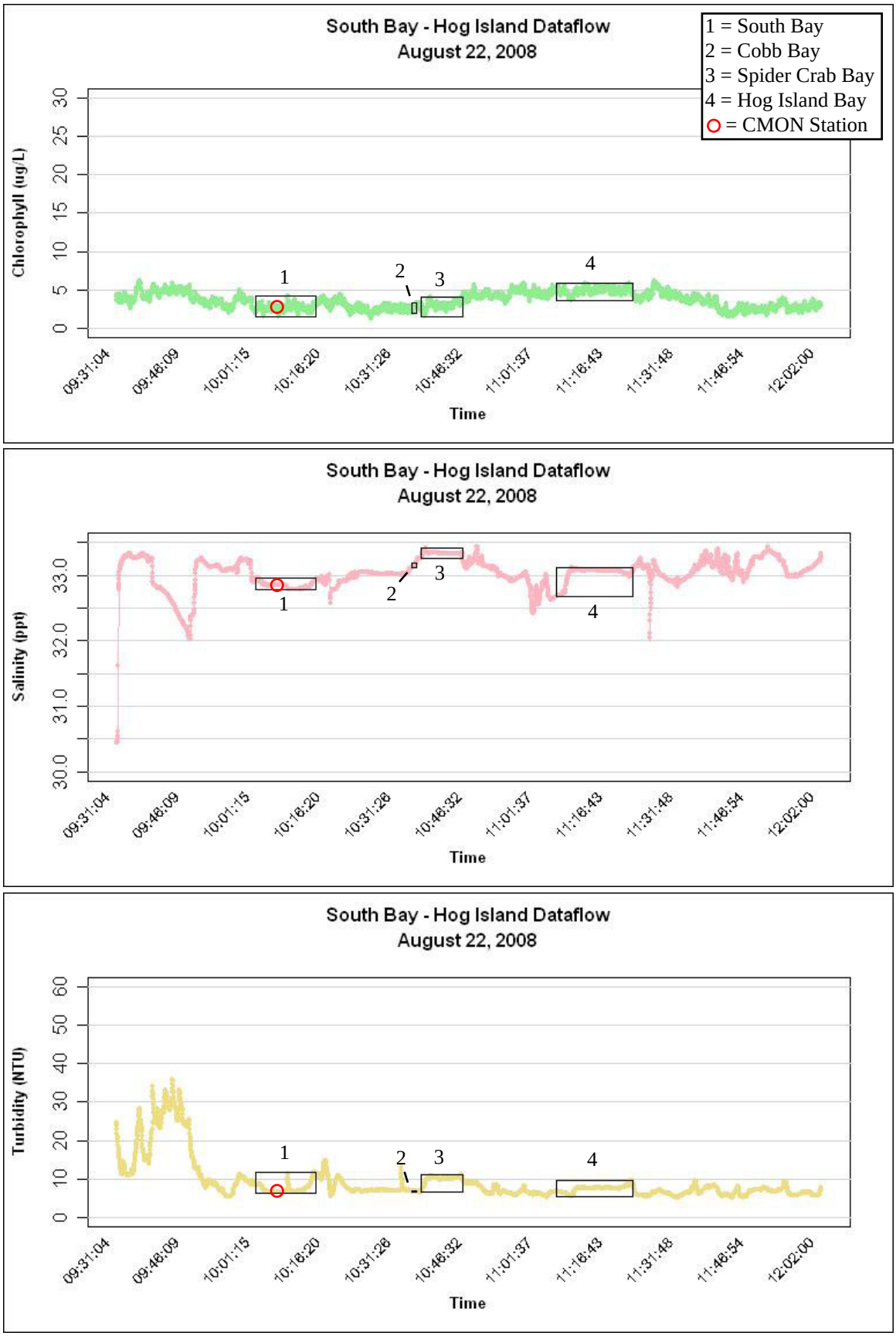

South Bay - Hog Island Dataflow
August 22, 2008
1 = South Bay
2 = Cobb Bay
3 = Spider Crab Bay
4 = Hog Island Bay
= CMON Station
Chlorophyll (ug/L)
0
5
10
15
20
25
30
1
2
3
4
09:31:04
09:46:09
10:01:15
10:16:20
10:31:28
10:46:32
11:01:37
11:16:43
11:31:48
11:46:54
12:02:00
Time
South Bay - Hog Island Dataflow
August 22, 2008
Salinity (ppt)
30.0
31.0
32.0
33.0
1
2
3
4
09:31:04
09:46:09
10:01:15
10:16:20
10:31:28
10:46:32
11:01:37
11:16:43
11:31:48
11:46:54
12:02:00
Time
South Bay - Hog Island Dataflow
August 22, 2008
Turbidity (NTU)
0
10
20
30
40
50
60
1
2
3
4
09:31:04
09:46:09
10:01:15
10:16:20
10:31:28
10:46:32
11:01:37
11:16:43
11:31:48
11:46:54
12:02:00
Time

Figure 8d

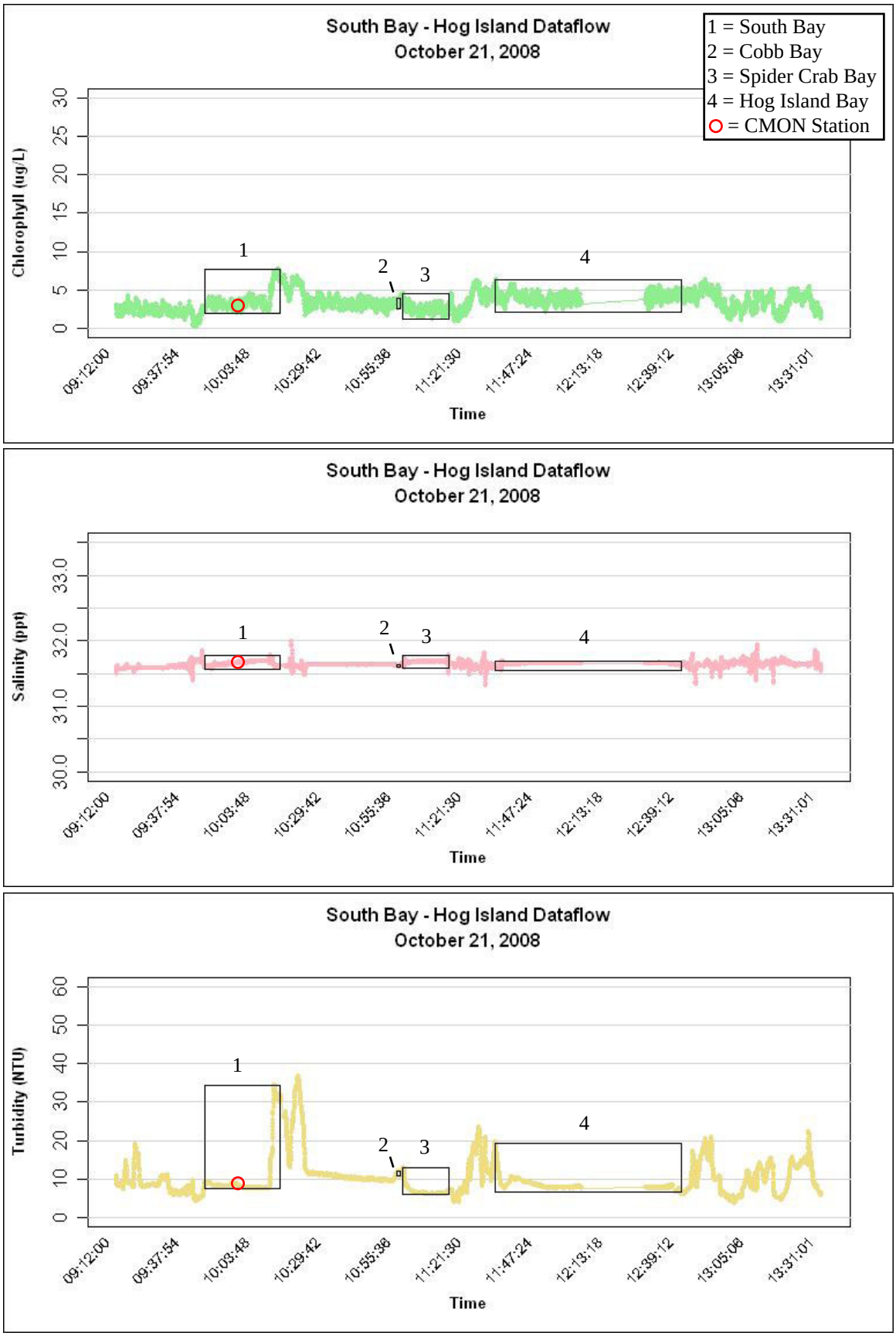

South Bay - Hog Island Dataflow
October 21, 2008
1 = South Bay
2 = Cobb Bay
3 = Spider Crab Bay
4 = Hog Island Bay
= CMON Station
Chlorophyll (ug/L)
0
5
10
15
20
25
30
1
2
3
4
09:12:00
09:37:54
10:03:48
10:29:42
10:55:36
11:21:30
11:47:24
12:13:18
12:39:12
13:05:06
13:31:01
Time
South Bay - Hog Island Dataflow
October 21, 2008
Salinity (ppt)
30.0
31.0
32.0
33.0
1
2
3
4
09:12:00
09:37:54
10:03:48
10:29:42
10:55:36
11:21:30
11:47:24
12:13:18
12:39:12
13:05:06
13:31:01
Time
South Bay - Hog Island Dataflow
October 21, 2008
Turbidity (NTU)
0
10
20
30
40
50
60
1
2
3
4
09:12:00
09:37:54
10:03:48
10:29:42
10:55:36
11:21:30
11:47:24
12:13:18
12:39:12
13:05:06
13:31:01
Time

Figure 9a

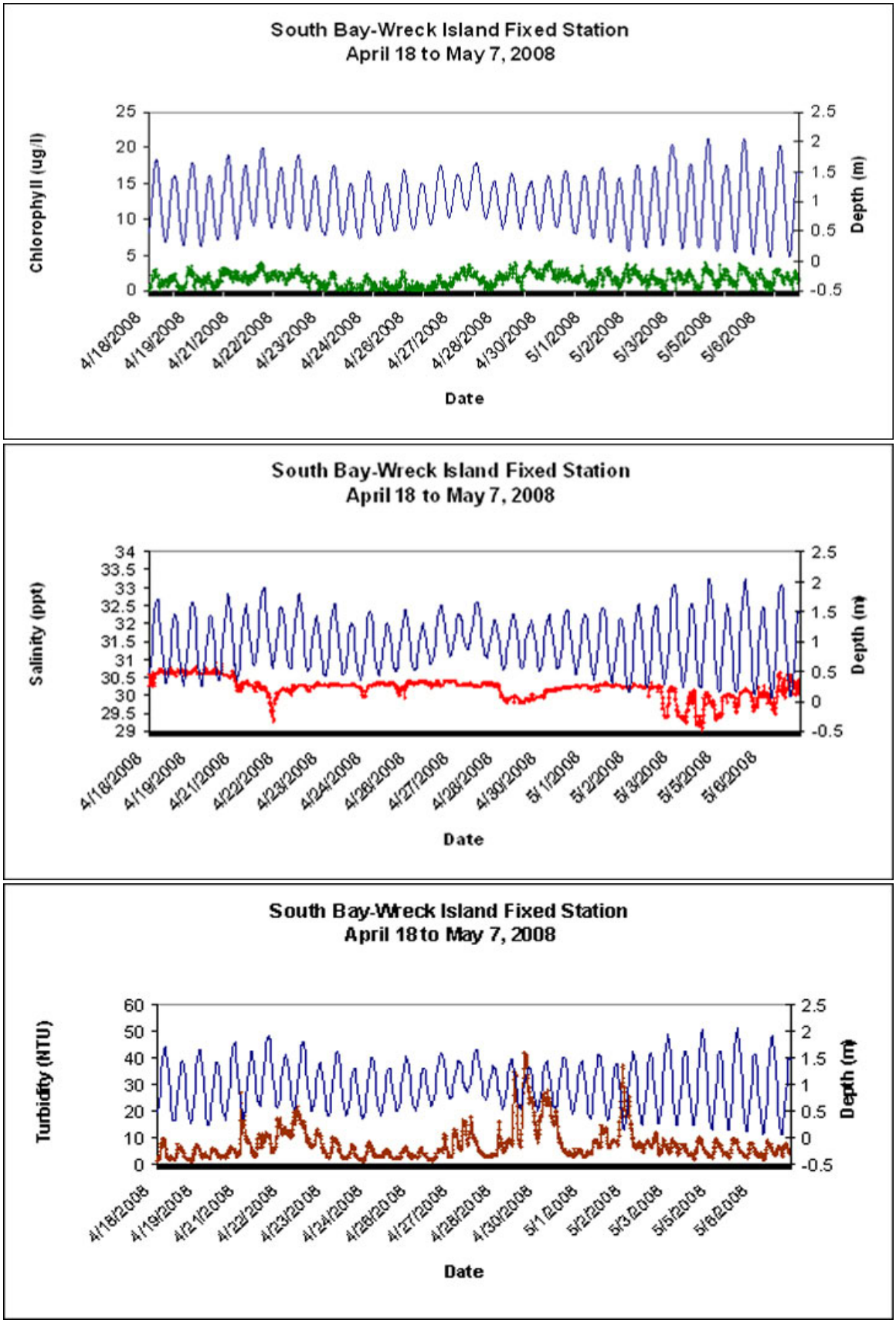

South Bay-Wreck Island Fixed Station
April 18 to May 7, 2008
Chlorophyll (ug/l)
Depth (m)
Date
South Bay-Wreck Island Fixed Station
April 18 to May 7, 2008
Salinity (ppt)
Depth (m)
Date
South Bay-Wreck Island Fixed Station
April 18 to May 7, 2008
Turbidity (NTU)
Depth (m)
Date

Figure 9b

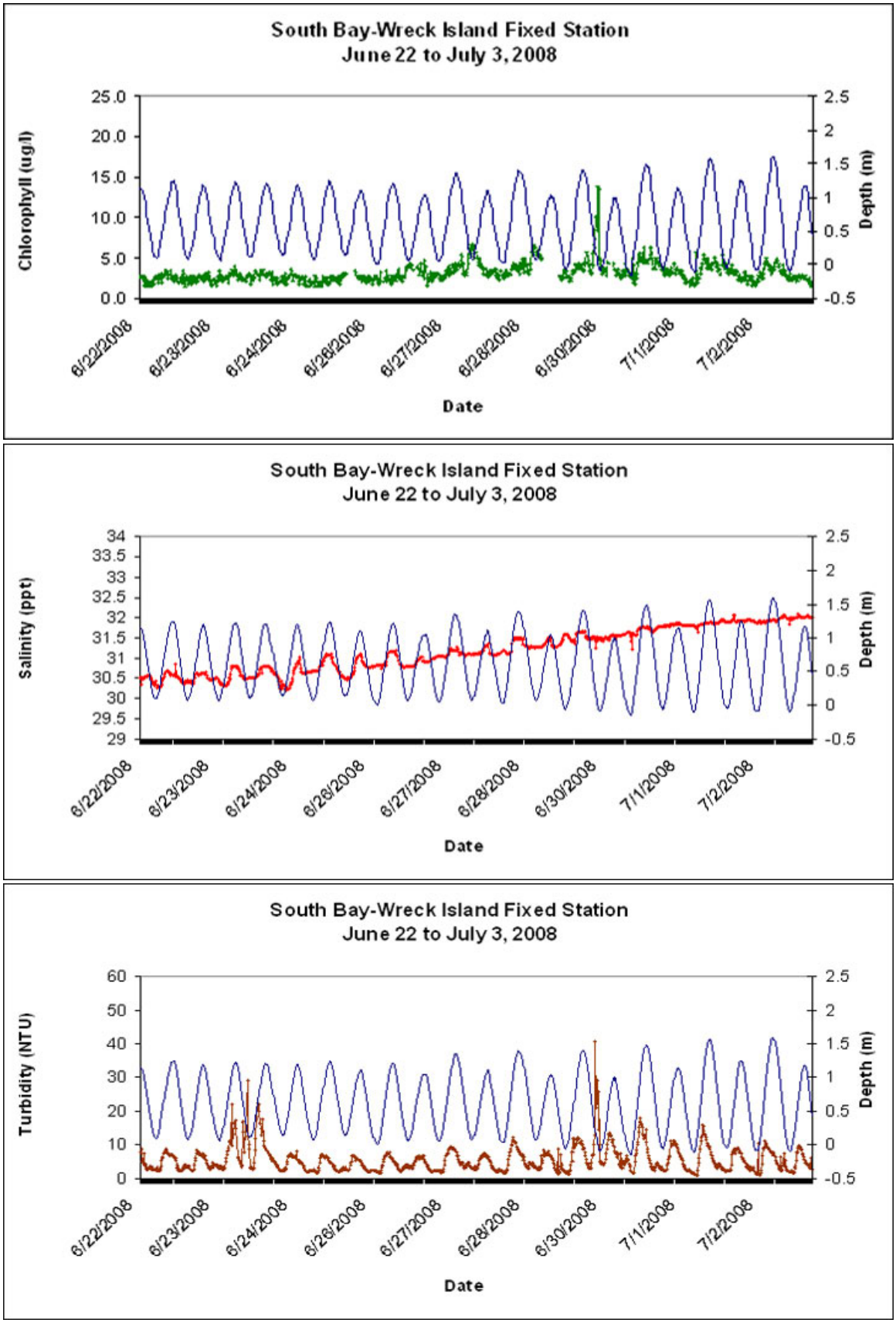

South Bay-Wreck Island Fixed Station
June 22 to July 3, 2008
Chlorophyll (ug/l)
Depth (m)
Date
South Bay-Wreck Island Fixed Station
June 22 to July 3, 2008
Salinity (ppt)
Depth (m)
Date
South Bay-Wreck Island Fixed Station
June 22 to July 3, 2008
Turbidity (NTU)
Depth (m)
Date
6/22/2008
6/23/2008
6/24/2008
6/26/2008
6/27/2008
6/28/2008
6/30/2008
7/1/2008
7/2/2008

Figure 9c

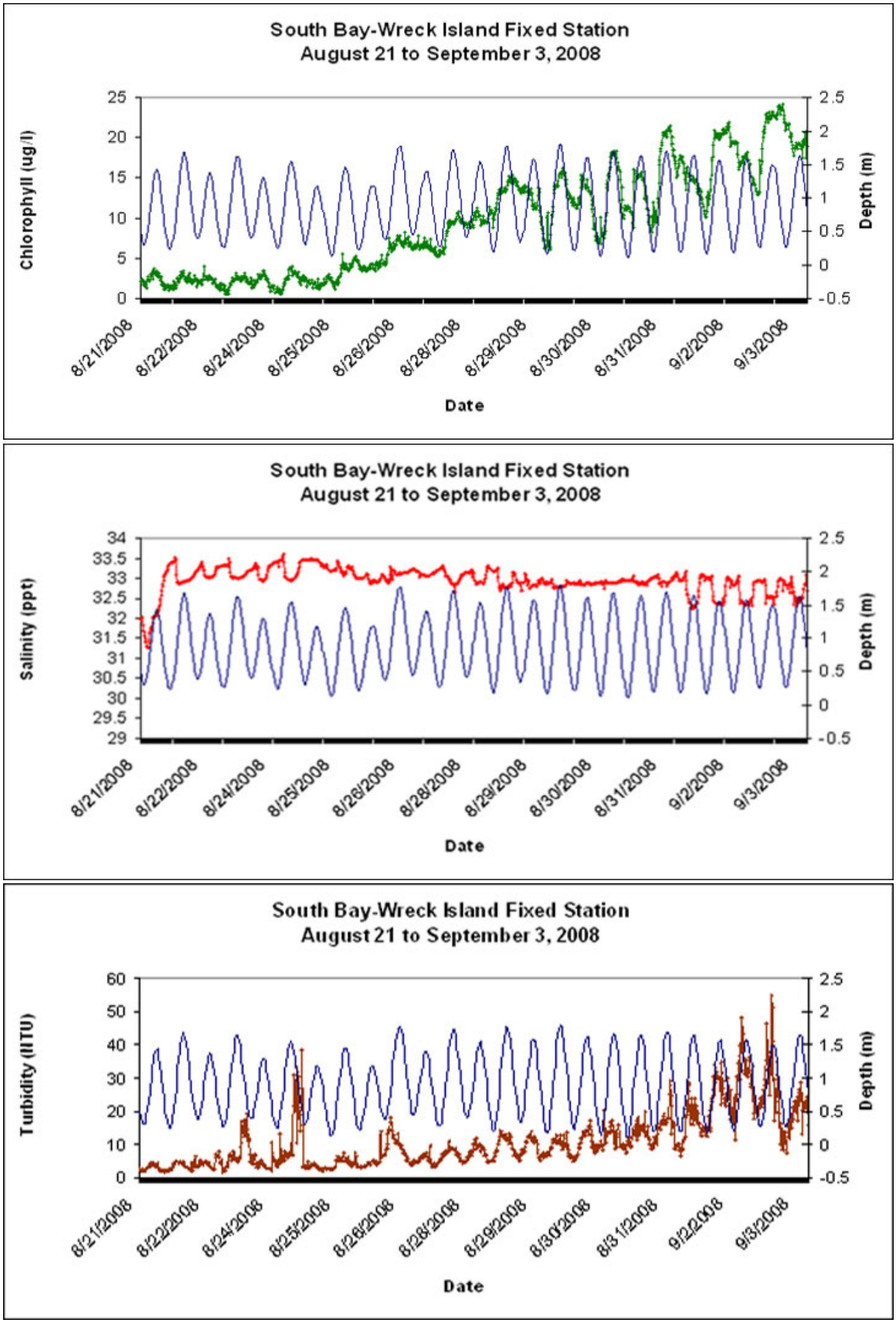
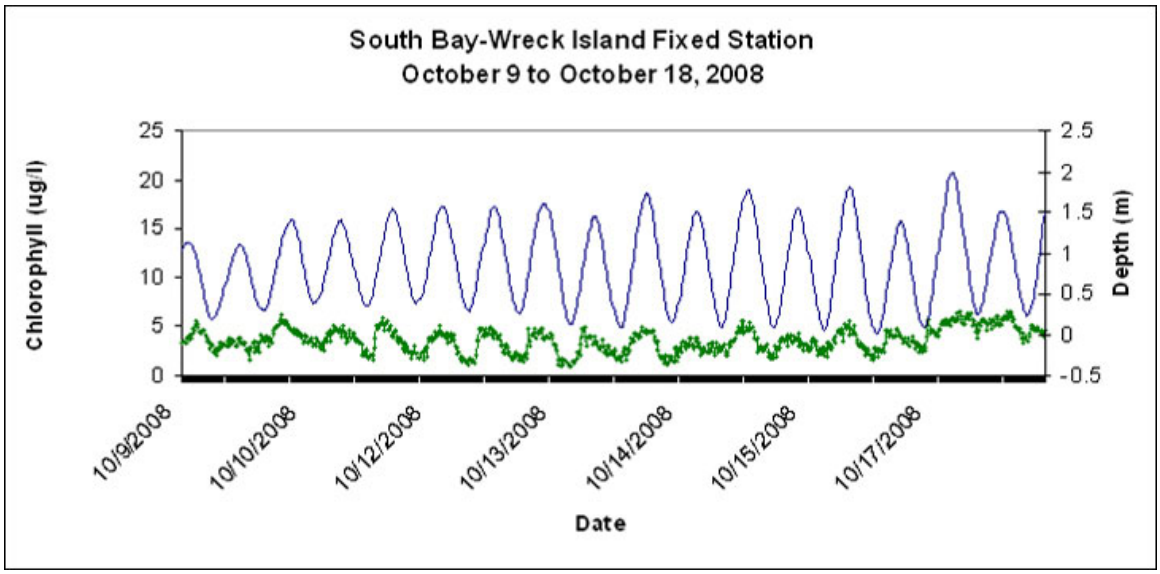
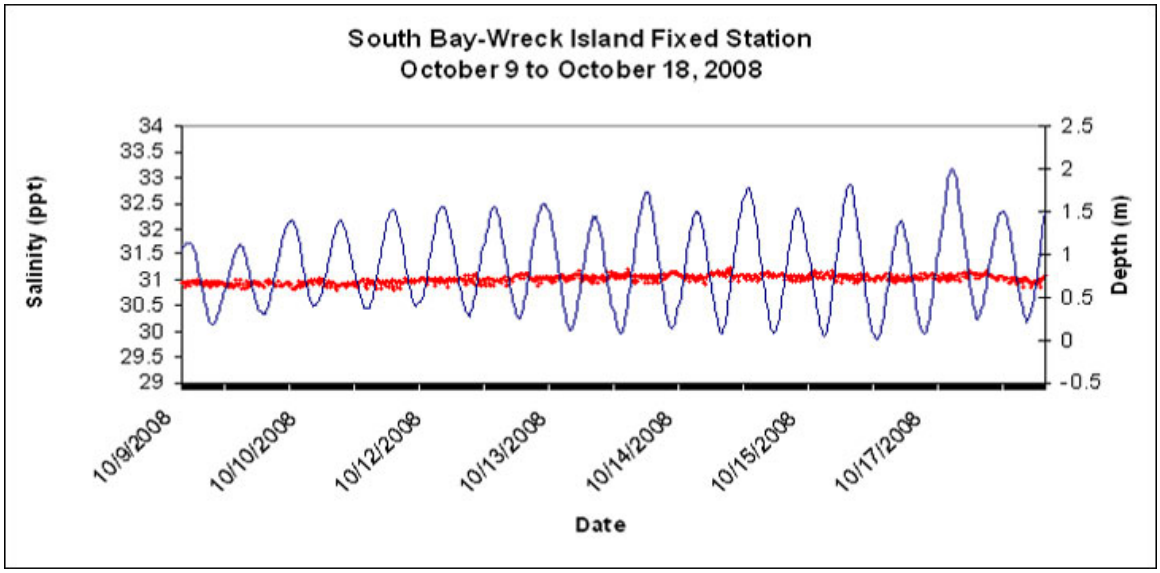

South Bay-Wreck Island Fixed Station
August 21 to September 3, 2008
Chlorophyll (ug/l)
Depth (m)
Date
South Bay-Wreck Island Fixed Station
August 21 to September 3, 2008
Salinity (ppt)
Depth (m)
Date
South Bay-Wreck Island Fixed Station
August 21 to September 3, 2008
Turbidity (NTU)
Depth (m)
Date
8/21/2008
8/22/2008
8/24/2008
8/25/2008
8/26/2008
8/28/2008
8/29/2008
8/30/2008
8/31/2008
9/2/2008
9/3/2008

Figure 9d


South Bay-Wreck Island Fixed Station
October 9 to October 18, 2008
Chlorophyll (ug/l)
Depth (m)
Date
10/9/2008
10/10/2008
10/12/2008
10/13/2008
10/14/2008
10/15/2008
10/17/2008


South Bay-Wreck Island Fixed Station
October 9 to October 18, 2008
Salinity (ppt)
Depth (m)
Date
10/9/2008
10/10/2008
10/12/2008
10/13/2008
10/14/2008
10/15/2008
10/17/2008

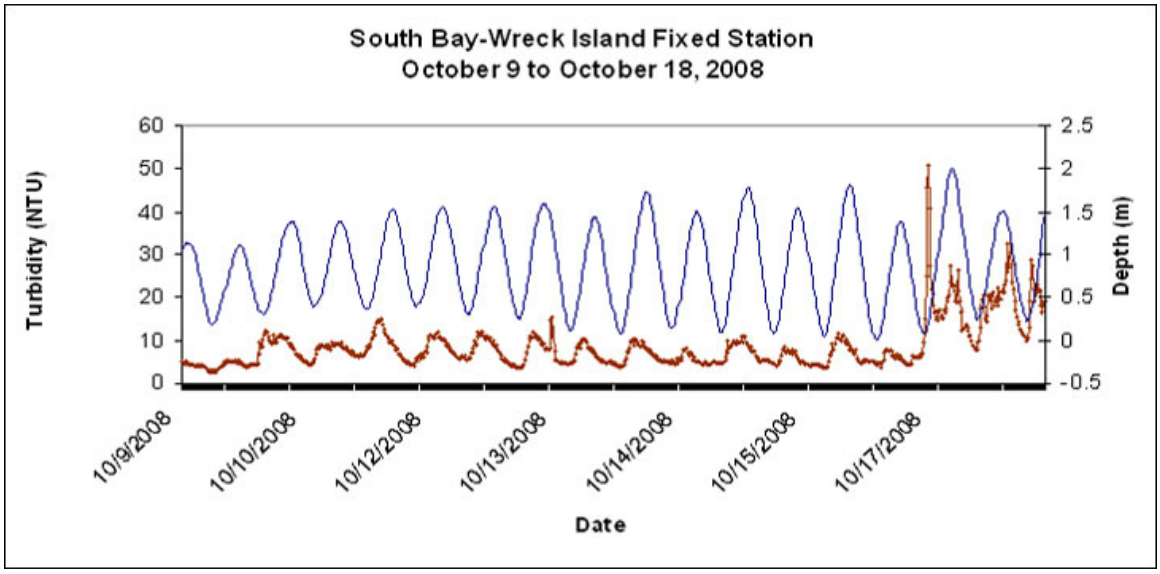

South Bay-Wreck Island Fixed Station
October 9 to October 18, 2008
Turbidity (NTU)
Depth (m)
Date
10/9/2008
10/10/2008
10/12/2008
10/13/2008
10/14/2008
10/15/2008
10/17/2008

Figure 10

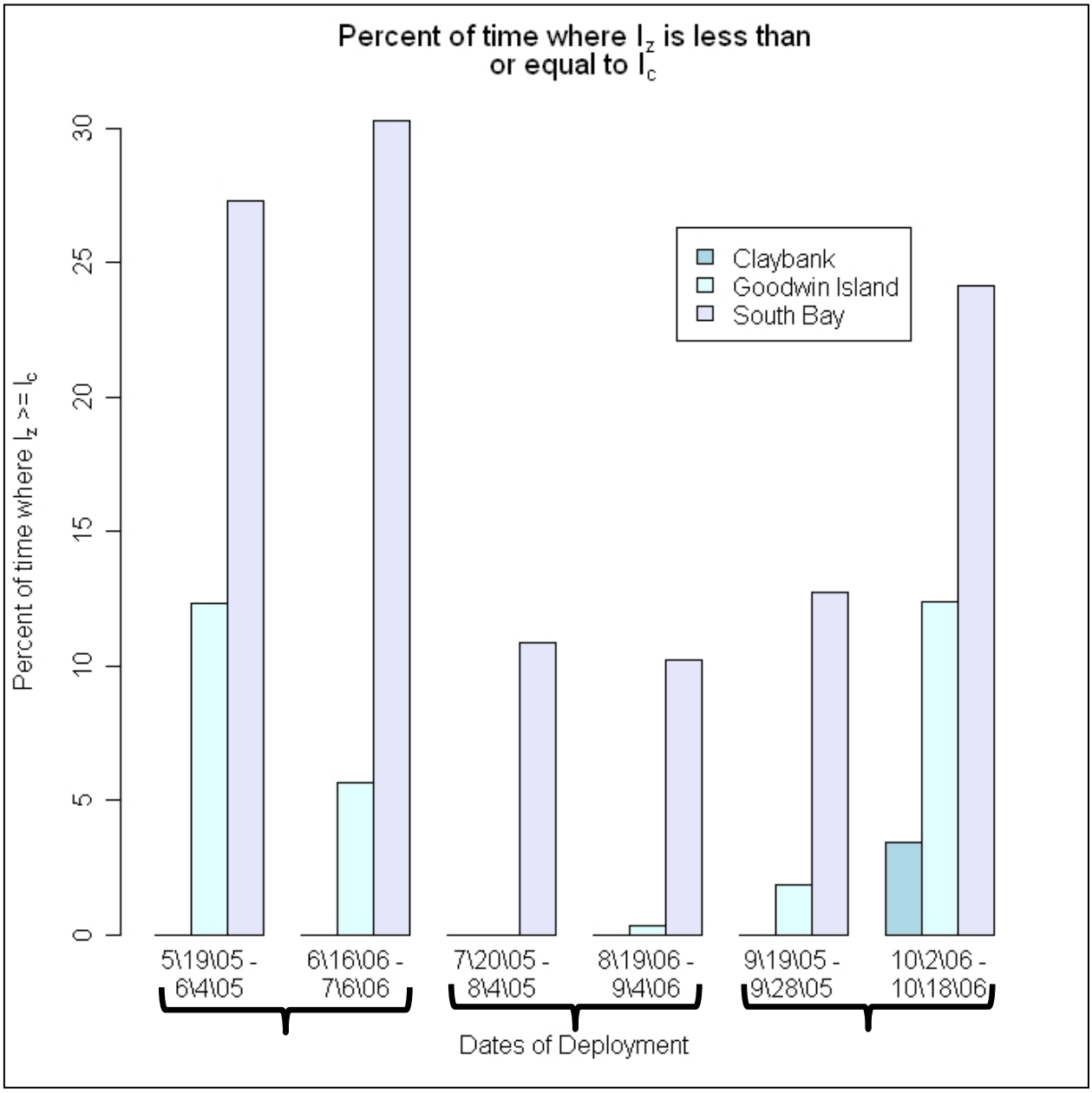
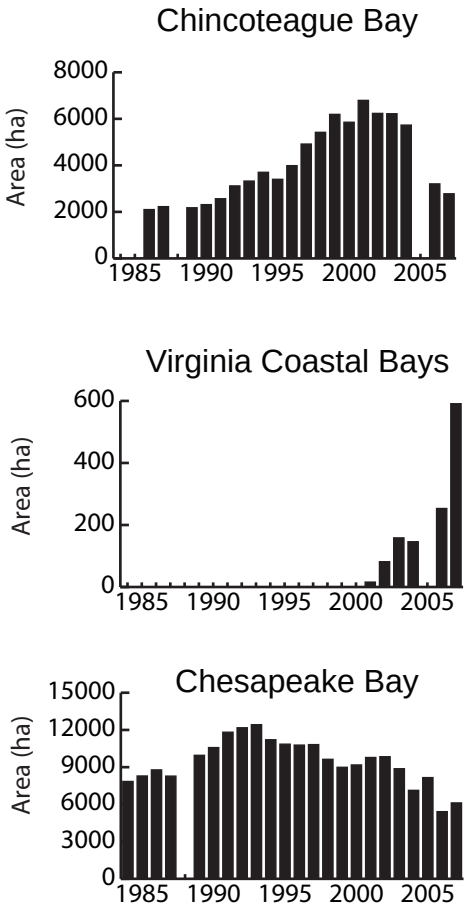

Percent of time where I_z is less than or equal to I_c
Percent of time where $I_z >= I_c$
0
5
10
15
20
25
30
Claybank
Goodwin Island
South Bay
5\19\05 - 6\4\05
6\16\06 - 7\6\06
7\20\05 - 8\4\05
8\19\06 - 9\4\06
9\19\05 - 9\28\05
10\2\06 - 10\18\06
Dates of Deployment

Figure 11


Chincoteague Bay
Area (ha)
8000
6000
4000
2000
0
1985
1990
1995
2000
2005
Virginia Coastal Bays
Area (ha)
600
400
200
0
1985
1990
1995
2000
2005
Chesapeake Bay
Area (ha)
15000
12000
9000
6000
3000
0
1985
1990
1995
2000
2005