Sebastian Inlet Channel
Comprehensive Seagrass Mitigation Program
Year 3 Monitoring Report

Prepared for

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1.0 Introduction

In August 2007 the Sebastian Inlet District (SID) completed the construction of a new navigation channel connecting Sebastian Inlet from Channel Marker No.18 westward to the Intracoastal Waterway (ICW). The purpose of this 3,120 ft long, 10.7-acre (5:1 side slope; -9 ft NGVD) channel extension was to provide the growing maritime community with a safe, clearly designated passage to/from the Atlantic Ocean as a matter of public safety and for the future protection of associated aquatic resources. To offset impacts to 3.08 acres of seagrass habitat and 7.62 acres of non-vegetated soft bottom, and pursuant to the Army Corps of Engineers (ACOE) and the Florida Department of Environmental Protection (FDEP) permits SAJ-2002-7868 (IP-TSD) and 05-264486-001, issued March of 2007, the permittee has provided the following to date:

1) The recovery of 459 planting units (179 *Halodule wrightii*; 279 *Syringodium filiforme*; 1 *Halophila johnsonii*) from the proposed channel alignment and subsequent planting of 41 propeller scars (hereafter, ‘propscars’), filling an estimated 366.95 m of linear damage.

2) The balance of financial support needed to install the Indian River County Main Relief Canal Pollution Control Structure, estimated to be $750,000.00. The structure came online in July of 2008.

3) The establishment and/or monitoring of the St. Johns River Water Management District (SJRWMD) fixed seagrass transect No. 51 plus 9 additional transects in the vicinity of the Main Relief Canal Outfall (Vero Beach, Florida); monitoring protocol and periodicity follows those of the SJRWMD. Three baseline monitoring events and four post-activation monitoring events have occurred.

4) The placement of “*Caution, Shallow Water, Seagrass Area*” signs clearly delineating 145 acres of the flood tidal shoal as seagrass habitat, protecting an initially estimated 110.26 acres (2007) of mixed meadow seagrasses. Current estimates (2010) place this value at 111.61 acres.

5) The quantification of seagrass coverage within the 6 designated protected areas (‘A’ thru ‘F’) using low-level, high resolution, digital orthophotography.

6) A complete inventory and tracking of annual changes to anthropogenic damage within the protected areas utilizing the approved classification schema.

7) The successful deployment of 2,031 Sediment Tubes® into 32 previously identified propeller-related scars, including 22 significant ‘blow-out’ features. Work was conducted in partnership with Seagrass Recovery, Inc.

The *Sebastian Inlet Channel Completion Project: Comprehensive Seagrass Mitigation Program Year 3 Monitoring Report* details the updated list of mitigation activities, as well as provides the third year monitoring results for the Inlet flood tidal shoal. A brief summary of findings for the

Vero Beach transects is also included. The *Report* has been divided into two sections based on the geography of the mitigation package: the flood tidal shoal at Sebastian Inlet and the Main Relief Canal Outfall in Vero Beach.

2.0 Sebastian Inlet, Florida

2.1. Aerial Image Analysis

2.1.1. General Approach

To assess changes in the submerged aquatic resources within the mitigation zone, as a potential direct or indirect result of waterway marker installation and channel construction, a GIS-based approach using low-level, digital aerial photography was implemented in June of 2007 and has continued annually thereafter. The following image analysis and field verification efforts had five primary objectives:

1) To quantify the aerial extent of existing seagrasses within the mitigation zone;

2) To assess post-construction changes to the spatial distribution and aerial extent of seagrass;

3) To identify and characterize all anthropogenic impacts (i.e., propeller-related scarring) within the mitigation zone using the approved classification schema;

4) To field verify (hereafter referred to as 'groundtruthing') the validity of observations made remotely; and

5) To refine the spatial resolution for which species-specific location data are collected and to assess any patterns therein.

2.1.2. Digital Orthophotography

The Sebastian Inlet District (SID) had originally contracted Pickett Surveying and Photogrammetry to meet the aerial photography needs for the Inlet monitoring; however, significant issues regarding the timeliness, and to a lesser extent, the quality of their 2007 deliverable, led to a decision to change firms for the 2008-2010 efforts. Aerial Cartographics of America, Inc. was alternatively selected to supply low-altitude, high-resolution, color Geotiff imagery for the 500-acre region of the shoal. An initial aerial flight was performed on May 28, 2010; however, due to poor water quality the aerial images were not sufficient for analysis. Aerial imagery of the flood tidal shoal was re-captured on August 23, 2010, during an incoming tide, at a negative scale of 1:4,800. Resultant print photography was then scanned at a scale of 1" = 50' and georectified to produce a Geotiff image with an effective ground pixel resolution of 0.25' (Figures 1 and 2).

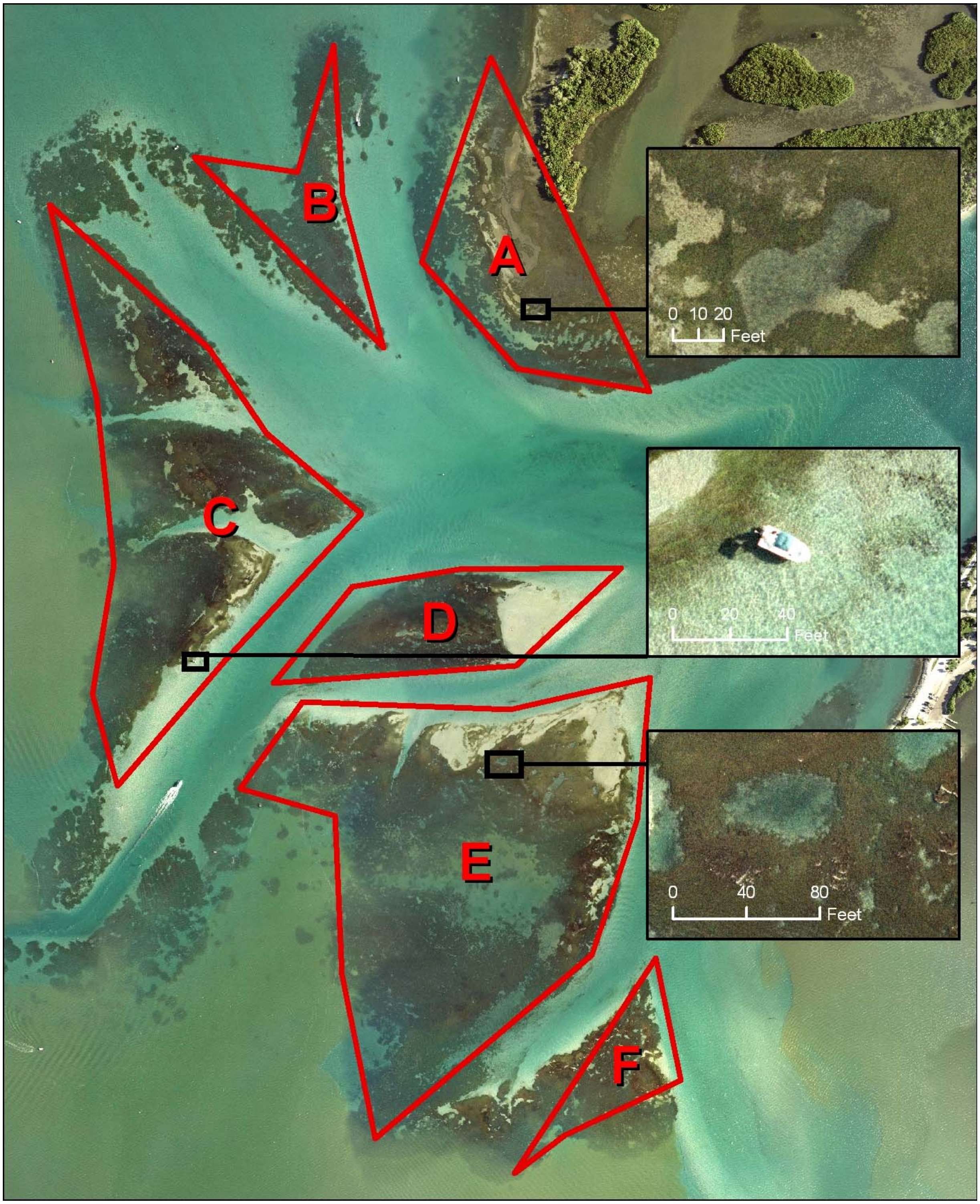


Figure 1. Geotiff of the Sebastian Inlet flood tidal shoal (Florida). The image was taken August 23, 2010 by Aerial Cartographics of America, Inc. for the Sebastian Inlet District. Callouts depict the level of resolution at various scales of observation.

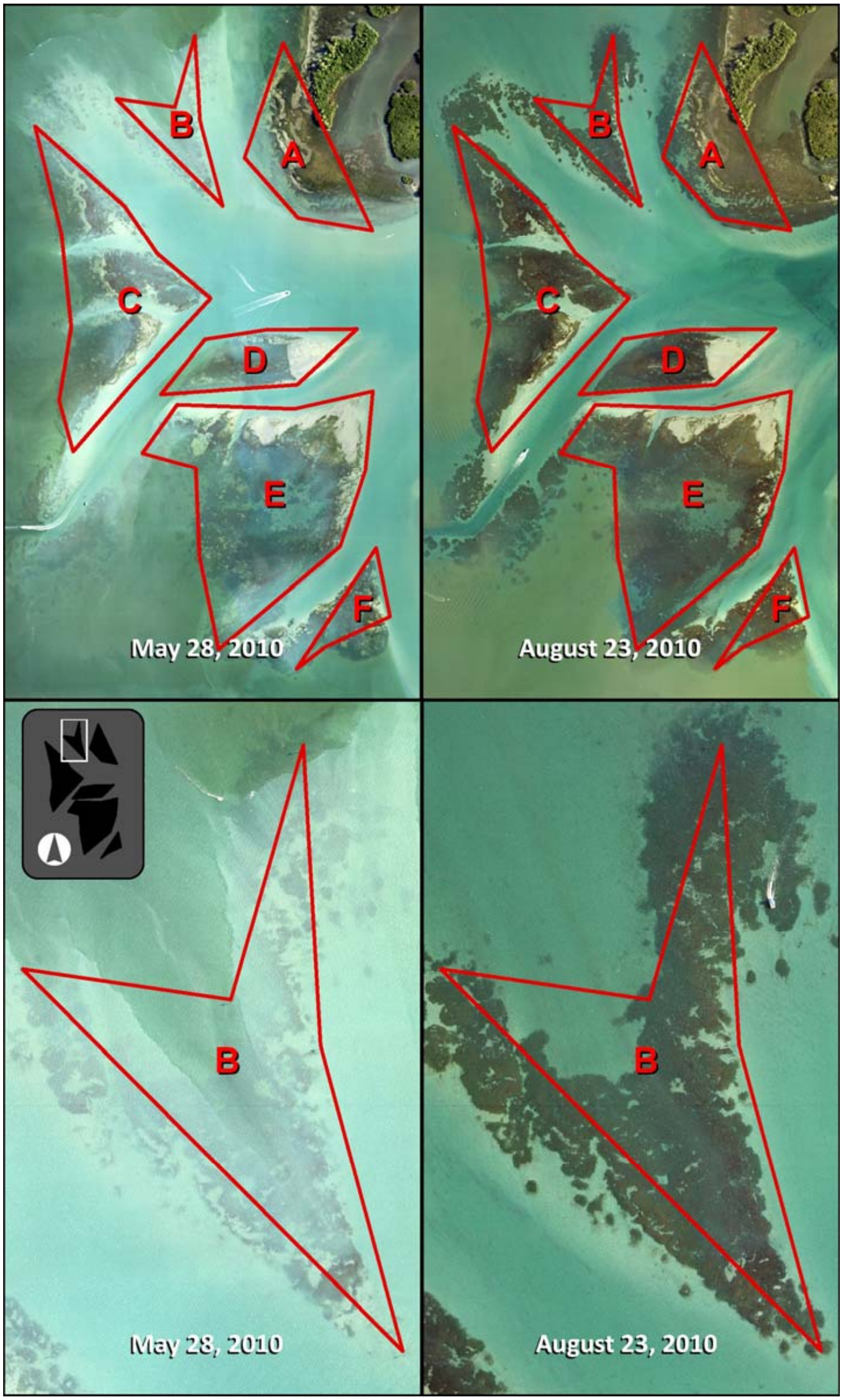


Figure 2. Side by side comparison of aerial imagery collected on May 28, 2010 (left) and August 23, 2010 (right). Due to the poor water quality, the images collected in May 2010 were not acceptable for analysis.

2.1.3. 2010 Seagrass Coverage

To estimate seagrass coverage within the mitigation zone, aerial photography was assessed for the presence or absence of perceived seagrasses using the Environmental Systems Research Institute (ESRI) ArcGIS software, ArcMap 9.3.1 and recorded manually as a polygonal feature class. All GIS analyses were conducted using source data projected in the State Plane system for East Florida:

Projected Coordinate System:
NAD_1983_HARN_StatePlane_Florida_East_FIPS_0901_Feet
Projection: Transverse_Mercator
False_Easting: 656166.66666667
False_Northing: 0.00000000
Central_Meridian: -81.00000000
Scale_Factor: 0.99994118
Latitude_Of_Origin: 24.33333333
Linear Unit: Foot_US

Geographic Coordinate System: GCS_North_American_1983_HARN
Datum: D_North_American_1983_HARN
Prime Meridian: Greenwich
Angular Unit: Degree

Generally, the distinction between seagrass and the surrounding habitat was made while viewing the photography at an absolute resolution of 1:400 to 1:500. Figure 3 depicts the estimated extent of seagrass and oyster habitat in Zone A in 2010. In most cases, water depth and clarity provided a seemingly clear view of the benthos, with little ambiguity regarding bed boundaries. However, during systematic sweeps of the image, several locations were visually skewed by wave activity, turbidity, color and/or artifacts of image manipulation made during production. These locations, and all positions of uncertainty (N=256) were carefully recorded on a separate point feature class and visited during the field verification or 'groundtruthing' exercise (*see Section 2.2 'Groundtruthing' below*).

The finalized seagrass coverage feature class (post-groundtruthing) yielded 111.61 acres of seagrass, equivalent to 76.97% of the mitigation zone (Figure 4). Zone-specific seagrass acreage estimates ranged from 4.60 (Zone F) to 45.89 acres (Zone E) with percent cover values (i.e., the percentage of the zone area covered by seagrasses) from 52.20% (Zone D) to 79.49% (Zone E). A complete listing of zone values can be found in the inset table of Figure 4.

2.1.4. Change Analysis

To estimate changes in the distribution of seagrass within the flood tidal shoal, and to infer the influence of signage on their expansion, we compared finalized seagrass coverage feature classes from 2009 and 2010 and from 2007 and 2010 for regions of 'Gain' and 'Loss'. ESRI ArcGIS 9.3.1 was used to cut the areas of non-overlap from alternating comparisons of the two datasets, leaving a remaining portion as a static region of 'No Change'. A visual depiction of these changes can be seen in Figures 5 and 6.

Figure 3. ESRI feature class depicting the estimated extent of seagrass and oyster habitat within Zone A in 2010.

Figure 4. ESRI feature class depicting the estimated extent of seagrass within the mitigation area in 2010. The associated table summarizes area and percent coverages by Zone. Aerial image taken August 23, 2010.

2.1.4.1. 2009 – 2010

From 2009 to 2010, a total of 9.54 acres of seagrass were lost and 11.17 acres gained, yielding a shoal-wide, net increase of 1.63 acres of seagrass (Figure 7). Net values ranged from -0.69 to 1.12 acres (Figure 7). The majority of this change occurred in Zones B and E. Zone B experienced a net increase of 1.12 acres from 2009-2010 while Zone E showed a net decrease of 0.69 acres over the same time period. Every zone with the exception of Zone E exhibited some degree of increase relative to their 2009 distributions.

Cursory examination of these data suggests that the seagrass changes were due to the opening and closing of internal gaps and more importantly, the expansion/retraction of the seagrass beds at the margins. Perhaps the best indications of seagrass bed expansion/retraction occurred in Zones B and E. Zone B was comprised mostly of 'new growth' while Zone E consisted mostly of seagrass losses. In previous years, considerable loss of seagrass was observed on the eastern margin of Zone D and the northern edge of Zone E, possibly due to sediment accumulation and subsequent burial of seagrasses. From 2009-2010, this reduction of seagrass has continued and progressed toward the interior of Zones D and E; however, unlike the previous years, seagrass growth is beginning to occur at the eastern and northern boundaries of Zones D and E, respectively.

2.1.4.2. 2007 – 2010

From 2007 to 2010, a total of 12.72 acres of seagrass were lost and 14.06 acres gained, yielding a shoal-wide, net increase of 1.34 acres of seagrass (Figure 8). Net values for each zone were less than 5 acres and ranged from -2.17 acres (Zone E) to 4.43 acres (Zone C). The majority of change observed on the flood shoal from 2007 to 2010 occurred in Zone C, which saw a net increase of 4.43 acres; however every zone with the exception of Zones B (1.61 acres) and C (4.43 acres) exhibited some degree of decrease relative to their 2007 distributions.

Closer examination of the 2007-2010 data suggests that the seagrass changes were mostly due to the expansion/retraction of the seagrass beds at the margins. Zones B and C were comprised mostly of 'new growth', extending the meadow further, toward the mitigation boundaries while Zones D and E were comprised mostly of seagrass losses. Considerable loss of seagrass was observed on the eastern margin of Zone D (Figure 9) and the northern edge of Zone E, possibly due to sediment accumulation and subsequent burial of seagrasses. This trend follows the excavation of the inlet sand trap for beach fill in 2007 and the subsequent filling and overflow of the sand trap from 2007 to 2010.

Two of the success criteria outlined in the ACOE (Special Condition 18, SAJ-2002-7868) and FDEP (Special Condition 23, File Number 05-264486-001) permits are: 1) the increase of submerged aquatic vegetation (SAV) on the flood shoal over time and 2) the overall percentage of SAV found on the flood shoal has improved in health, distribution, and abundance. As previously discussed, seagrass coverage has slightly increased on the flood shoal over the past three years (2007: 110.26 acres; 2010: 111.61 acres), indicating the stability, health and resilience of the seagrass community at Sebastian Inlet.

Figure 5. Spatial distribution of inter-year change in seagrass coverage within the mitigation boundaries. Gains are depicted as green, losses red, and areas consistent between years, gray. Analysis included 2009-2010 data. Zones A thru F are named in counterclockwise order originating from the upper right.

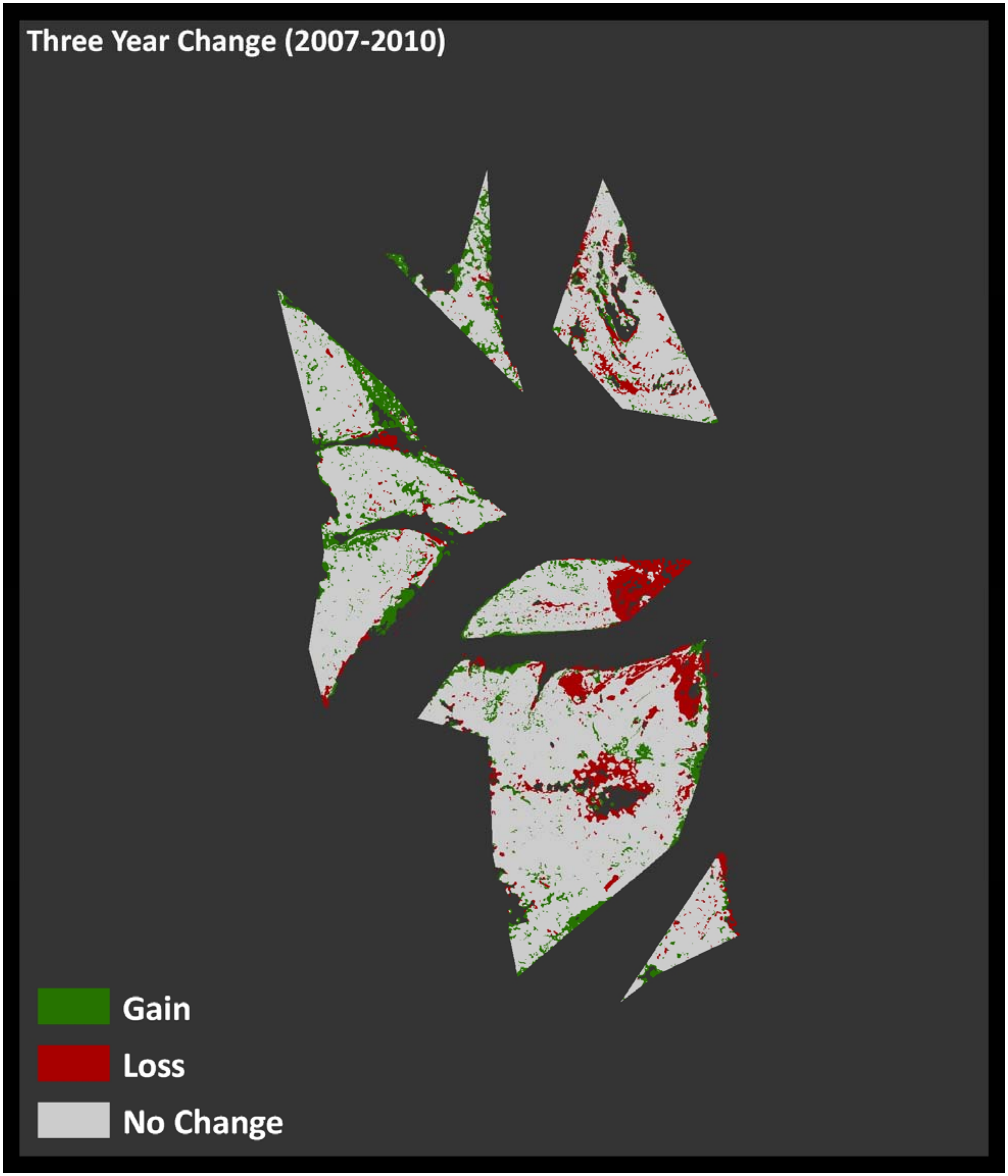


Figure 6. Spatial distribution of inter-year change in seagrass coverage within the mitigation boundaries. Gains are depicted as green, losses red, and areas consistent between years, gray. Analysis included 2007-2010 data. Zones A thru F are named in counterclockwise order originating from the upper right.

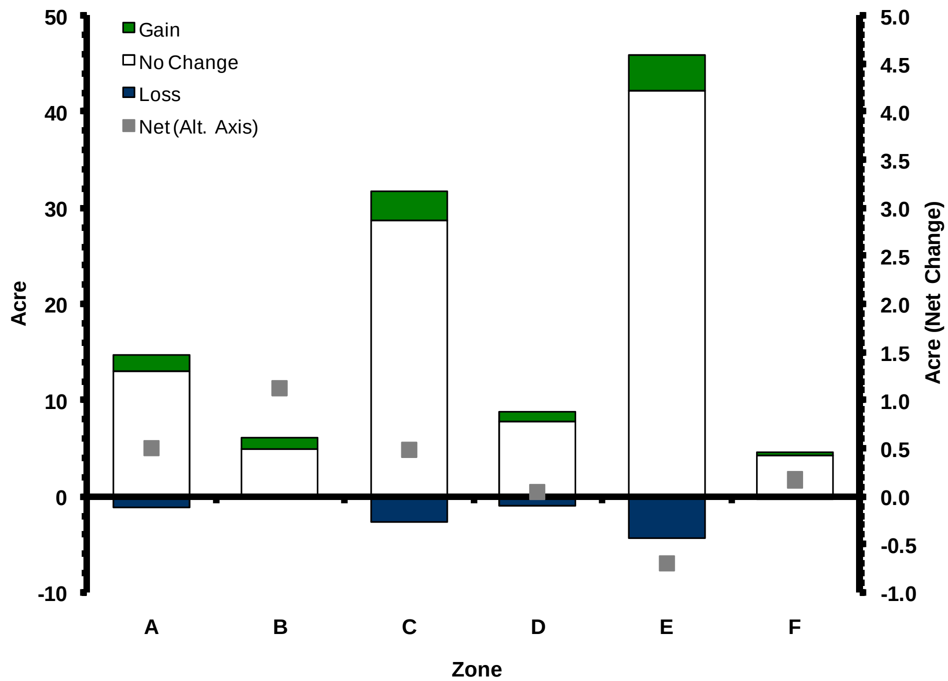


Figure 7. Zone-specific changes in seagrass cover between 2009 and 2010. Net change in total acreage depicted on alternate axis.

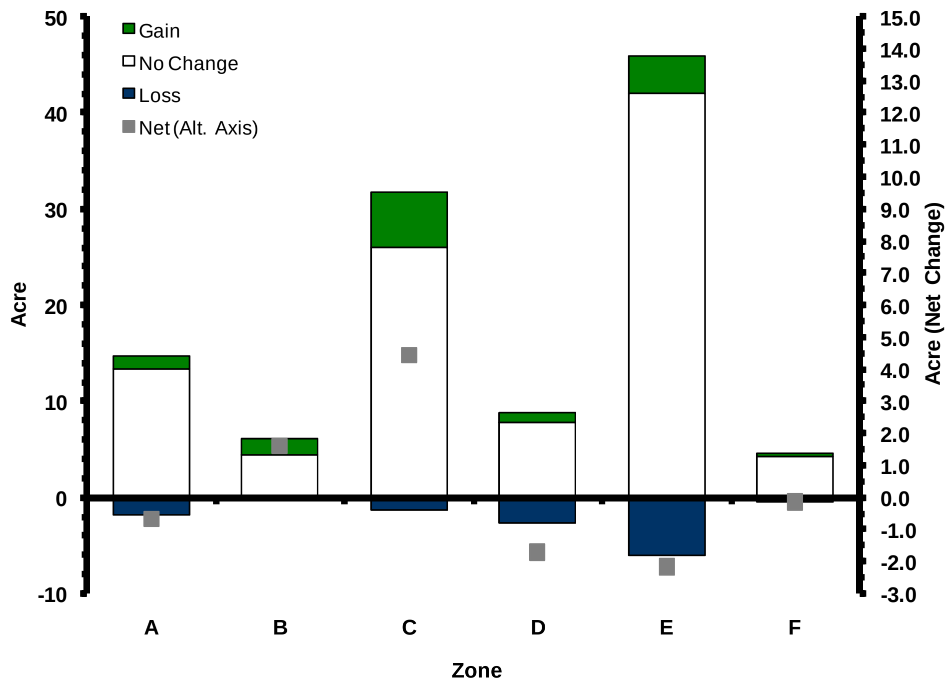


Figure 8. Zone -specific changes in seagrass cover between 2007 and 2010. Net change in total acreage depicted on alternate axis.

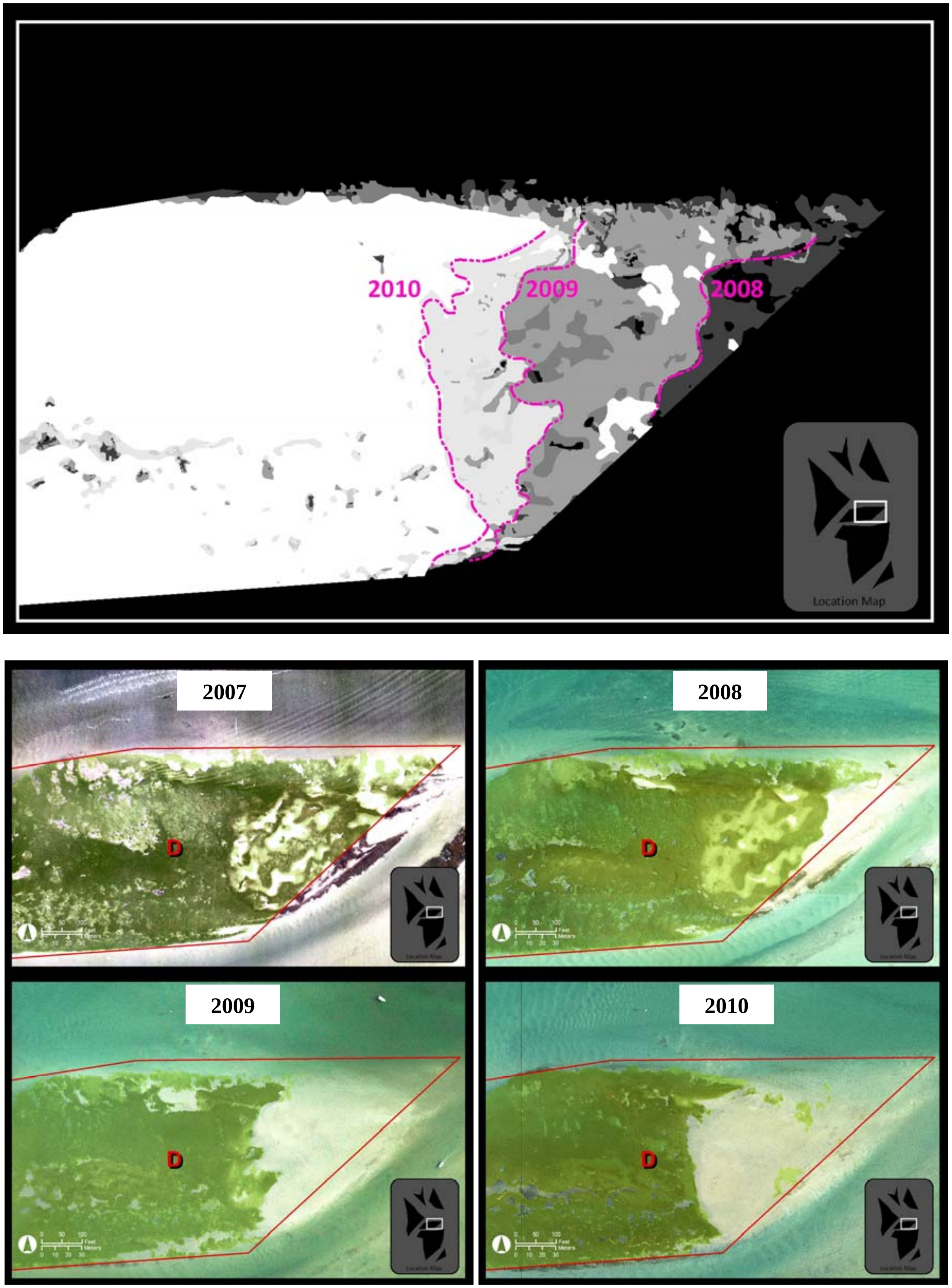


Figure 9. Graphics showing the westward retreat of the seagrass edge in Zone D from 2007 to 2010. Note that in the top graphic the edge of the seagrass bed in 2007 was at the eastern boundary of Zone D**.**

2.1.4.3. Qualitative Comparison (2009 – 2010)

A quick qualitative assessment was performed on the aerial imagery collected in 2009 and 2010 (Figure 10). A notable decrease in seagrass coverage was observed within the interior channels of Zone C from 2009 to 2010. The eastern sides of these channels, previously occupied by *Halophila johnsonii* in 2009, were void of seagrasses in 2010 (Figure 10). This absence of *H. johnsonii* is likely due to the ephemeral nature of this species. In 2009 the aerial imagery was collected in June during peak growing season while the 2010 imagery was not successfully captured until late August. Notable changes were also observed on the eastern side of Zone D and the northern edge of Zone E. As in previous years, the seagrass edges continued to move toward the interior of the Zones; however, new seagrass growth was apparent near the zone boundaries from 2009 to 2010 (Figure 10).

Figure 10. Locations of noteworthy differences (white rectangles) between the 2009 (left) and 2010 (right) aerial images.

2.2. Groundtruthing

2.2.1. Objectives

Any attempt to characterize benthic composition from high-resolution aerials presents a suite of technical challenges, including changing optical properties of water with depth, variations in water constituents across the spatial extent of an image, reflections caused by an imperfect water surface, and shadows from taller features. These issues were exacerbated at the Inlet by the confluence of two distinctly different water bodies (i.e., tannin-rich lagoonal water and comparatively clearer, but at times silt containing, Atlantic Ocean water) creating a heterogeneous mixture of optical properties over the range of required depths.

Predicting the strength of these factors and attempting to model their influence on the spectral return of an image would have required real-time physiochemical data at scales well beyond the scope of this project; however, general estimates of our method effectiveness (or limitations therein) were taken during the 2007 baseline monitoring event and presented in the *Initial Conditions* report. These efforts, which included depth analysis and patch size-specific measures, pointed toward a 30-100% accuracy for areas with verified seagrass at depths of less than 1.5 m (representing greater than 93.84% of the mitigation area) and between 70-100% accuracy overall. There was a general trend of underestimating seagrass coverage with depth (particularly for *Halophila* spp.).

During all monitoring events, methodological errors were confounded by lag time between aerial flight and actual physical groundtruthing (time needed to produce and review the aerials before fieldwork can be performed). During the 2010 monitoring, official groundtruthing efforts did not commence until September 20-21 and October 11-15, 2010 or 28+ days post-flight. In addition, subsurface visibility was significantly reduced on September 20-21, 2010 while conducting groundtruthing activities. These conditions limited the ability of PBS&J biologists to conduct the standard propscar and point-of-interest surveys by foot, and forced a substantial portion of the effort to be conducted via snorkel, inhibiting field of view and drastically reducing the ability to find and categorize shoal features. Due to high winds (>15 mph) on September 21, 2010, the field effort was postponed until weather improved the week of October 11, 2010. Despite these conditions, the sampling of the shoal was successfully accomplished using the results of the image analysis and guided by the latest in GIS/GPS technology, i.e. the use of Trimble Geo-XT handheld DGPS units, running ArcPad 7.0.1.

The objectives of the weeklong groundtruthing event were:

1) to confirm and catalogue potential anthropogenic damage to the shoal (*discussed in Section 2.3 Catalogue of Anthropogenic Damages*),

2) to field-verify points of uncertainty encountered during the image analysis,

3) to refine the original seagrass coverage GIS dataset using *in situ* mapping and field notation,

4) to conduct a year-two monitoring of sediment tube reparation sites (*discussed in Section 2.4 Active Restoration)*,

5) to conduct the year-three monitoring of transplant-repaired propscars (*discussed in Section 2.5 Seagrass Transplantation)*, and

6) to obtain adjacent seagrass species data for each position visited.

2.2.2. Results

Within the sampling periods September 20-21 and October 11-15, 2010, PBS&J biologists used handheld DGPS (Trimble Geo-XT, running ArcPad 7.0.1) to visit 590 potential propscars, 256 points of uncertainty, 32 sediment tube reparation sites, and two transplanted prop scars. Only those transplanted scars found in 2009 (n=2) were monitored in 2010. Figure 11 depicts the spatial distribution of the potential propscar and uncertain points.

Points of uncertainty had been identified during the image analysis and generally consisted of darkened (or lightened) areas inconsistent with the coloring of adjacent seagrasses, or other spectral anomalies potentially related to changes in seagrass density within contiguous beds, discontinuous epiphytic loads, or differences in underlying substrata. Physical confirmation of seagrass presence or absence at each of these sites consisted of a haphazard swim, resulting in a broad assessment of bottom type, as well as seagrass species (where applicable). The point feature class was then appended onsite and used for later refinement of the bed boundaries within the seagrass coverage GIS dataset. Additional field notation regarding seagrass status was recorded in transit between points and, using the ArcPad software, PBS&J biologists were able to confirm, in real-time, the accuracy of the GIS data during all point (position) changes on the shoal. In most cases, only minor adjustments were needed as the mapped features appeared to have accurately tracked even small changes in the edge-of-bed contours, including internal gaps on the order of 5 m^2. The finalized, 2010, seagrass GIS dataset can be seen in Figure 4 and was used in all acreage calculations reported within this document.

Of the 880 positions visited during the groundtruthing event, 846 were sampled for benthic composition and 695 positions contained seagrass. The remaining 151 positions sampled consisted of habitats other than SAV. Figure 12 depicts the locations of predominant species/species combinations observed on the shoal. Species-specific data revealed that 80% of all sites visited were either a combination of *Syringodium filiforme* and *Halodule wrightii* or monospecific beds of *S. filiforme* or *H. wrightii* (Figure 12; Table 1). Because the areas located north and south of the Sebastian Inlet Channel are considered *Halophila johnsonii* critical habitat, a separate figure was created, clearly showing the distribution of *H. johnsonii* within the mitigation area in 2010 (Figure 13). *H. johnsonii* was present at 2% of all sites visited, irrespective of density and composition (Figure 13; Table 1). This is a decrease from 2009 where *H. johnsonii* was observed at 8% of all sites visited. This decrease could be due to seasonal changes as the 2010 monitoring was conducted after peak growing season. The remaining 18% consisted of other species combinations (*Halophila decipiens, Halodule wrightii/Thalassia testudinum, Syringodium filiforme/H. decipiens, S. filiforme/H. wrightii/T. testudinum, S. filiforme/T. testudinum*) or no seagrass (~0.6% and ~17.8%, respectively; Table 1).

Figure 11. Location of potential propscars and points of uncertainty identified during the 2010 image analysis. Aerial photography provided by Aerial Cartographics of America, Inc, taken August 23, 2010.

Figure 12. Location of predominant species/species combinations obtained during the 2010 groundtruthing event.

Table 1. The percentage of sites sampled with each seagrass species/species combination observed during the 2010 groundtruthing event.

Seagrass Species/Species Combinations	Percentage of Sites
Halophila decipiens	0.1
Halophila johnsonii	1.1
Halodule wrightii	13.2
Halodule wrightii/Halophila johnsonii	0.6
Halodule wrightii/Syringodium filiforme/Halophila johnsonii	0.2
Halodule wrightii/Thalassia testudinum	0.1
Syringodium filiforme	27.3
Syringodium filiforme/Halophila decipiens	0.1
Syringodium filiforme/Halodule wrightii	39.1
Syringodium filiforme/Halodule wrightii/Thalassia testudinum	0.1
Syringodium filiforme/Thalassia testudinum	0.1
Percentage of Sites with Seagrass	**82.2**

Figure 13. Locations with *Halophila johnsonii* during the 2010 groundtruthing event.

2.3. Catalogue of Anthropogenic Damages

2.3.1. Methodology

To estimate the quantity and severity of anthropogenic impacts within the mitigation zone, PBS&J staff biologists systematically examined the aerial photography at an absolute resolution of 1:400 to 1:500 for the presence of linear and/or otherwise un-natural features of the shoal (e.g., propscars, blow-outs). In this manner 590 potential damages were identified and a GIS feature class was created depicting their respective locations (Figure 11).

During the September 20-21 and October 11-15, 2010 groundtruthing effort, PBS&J biologists used handheld DGPS (Trimble Geo-XT) to visit each of the positions, assessing them for validity. For locations that proved to be vessel-related damages, categorization of damage ‘types’ were made. Estimates of length and scouring depth (Type III only) were also recorded. The criteria for the classification of anthropogenic damages were as follows:

- Type I damage: scarring in which prop damage is limited to the partial loss of shoot biomass, without impacts to the rhizosphere or surrounding sediment;
- Type II damage: scarring with complete loss of aboveground biomass and little to no damage below the original sediment-water interface; and
- Type III damage: scarring with complete loss of seagrass and loss of sediment below the rhizosphere.

2.3.2. Accuracy

The overall accuracy of remotely determined scar locations was 32.03% (189 verified propscars out of 590 potential propscar locations; Zone A=44.44%, B=16.28%, C=20.95%, D=43.78%, E=29.55%, F=28.13%). Several factors likely contributing to error (Type 1 error, or false positive) include:

1) Type I scarring may have re-grown during the 28+ day lag between the photography and the survey.

2) Low visibility, especially on September 20-21, 2010, inhibited the panoramic view often required to identify Type I scarring in the field. Observations made via snorkel may have been too narrow in scope to adequately locate such minimal impacts in the field, thereby reducing Type I accuracy relative to what was visible in the August 23, 2010 aerial image.

3) High tidal currents often interacted with large canopy heights to produce seemingly linear features in otherwise undisturbed seagrass beds. Such hydrodynamically induced patterns may have been misinterpreted during photo interpretation of the aerial image.

4) Patchily distributed epiphytic loads and species composition often created a mosaic of spectral differences that mimicked scarring. These patterns may have been influenced by tidal currents.

In spite of the Type 1 or false positive errors, the method produced a serviceably accurate assessment of damage type distribution and was largely successful in identifying the most severe damages.

2.3.3. Summary of Damages

To assess the influence of depth on propscar distribution, we used bathymetric data from *Land and Sea Surveying Concepts,* June of 2007, to construct an inverse distance weighted interpolated raster file (IDW, cell size of 1 m^2) and extracted the underlying cell values for each of the 2010 propscar point data. In this way, we were able to obtain relatively recent depth information for 572 of the 590 potential propscar locations; however, all of the points from Zone A (N=18) did not coincide with the 2007 bathymetric survey and so were not included in further analysis. The summary of point data by zone was as follows: Zone A, N=0; Zone B, N=43; Zone C, N=148; Zone D, N=217; Zone E, N=132; Zone F, N=32.

The 181 confirmed scars for which interpolated water depths were available ranged from 0.20 m to 1.64 m with a mean water depth of 0.78±0.03 m (± SE; Figure 14). Damages were generally found wherever these water depths occurred; however, Type III scarring was most pronounced in Zone E, a pattern that included Zone D after standardizing for zone area (Figures 15 and 16). To standardize for zone area the number of verified Type I, II, and III propscars observed in each Zone in 2010 were divided by the total acreage of each Zone (Zone A=18.7 acres, Zone B=8.1 acres, Zone C=41 acres, Zone D=13.7 acres, Zone E=57.7 acres, and Zone F=5.8 acres). Similar to the previous year, Type III scarring was not observed in Zone F in 2010.

Mean scouring depths (below surrounding sediment) for Type III scars were somewhat consistent amongst zones in 2010, with the exception of Zone F where no Type III scars were observed, and ranged from 1.00 cm (Zone B, N=1) to 5.80±0.66 cm (Zone E, N=10) with an overall mean of 4.69±0.64 cm (N=21; Figure 17). This is similar to the overall mean of scouring depths reported in 2009, 4.13±0.69 cm (N=24) but drastically less than the mean reported in 2007, 7.14±0.92 cm (N=128). Mean length estimates for Type III scars varied amongst zones with values ranging from 6.40 m (Zones B and D, N=1 and 4, respectively) to 13.56±6.62 m in 2010 (Zone C, N=4; Figure 18). The overall mean length for Type III scars in 2010 was 10.80±1.97 m (N=21). When viewed in aggregate, the number and severity of propscars in 2010 tended to be concentrated to the south of the newly-constructed channel, particularly Zone D (Figure 16).

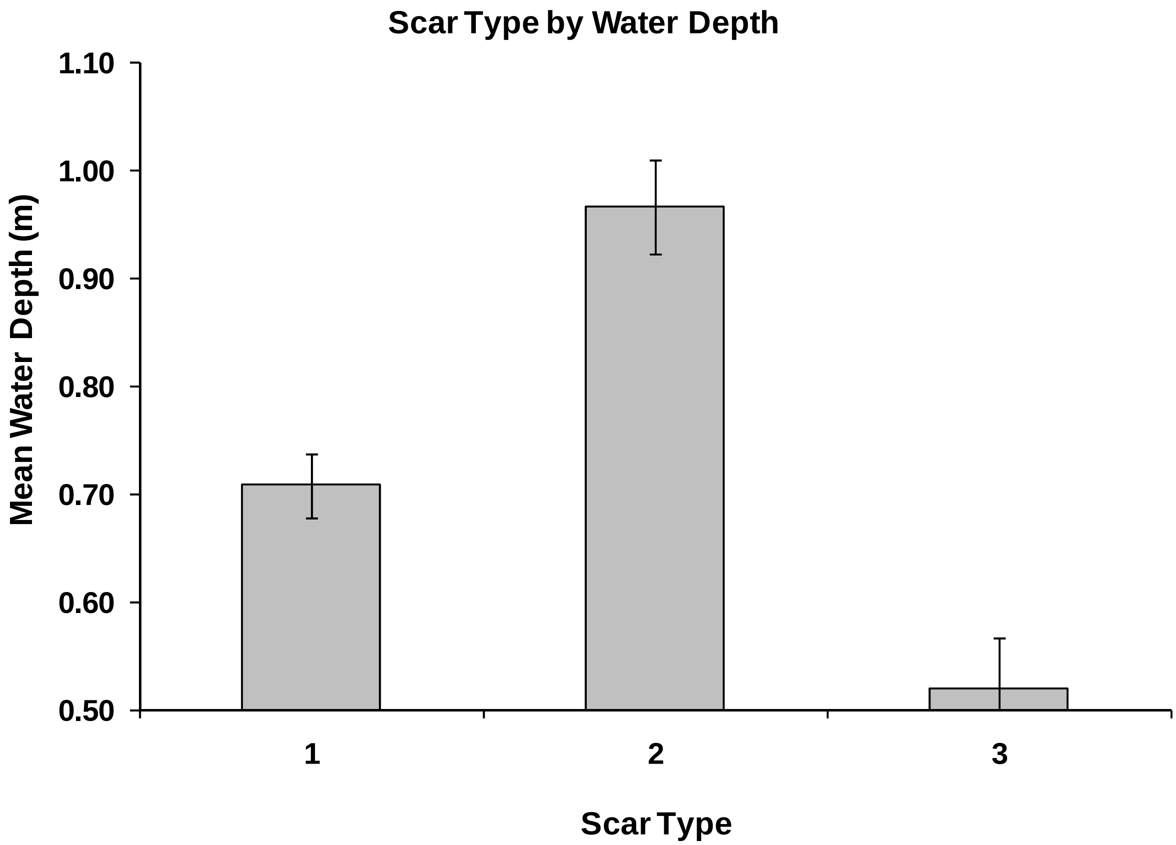
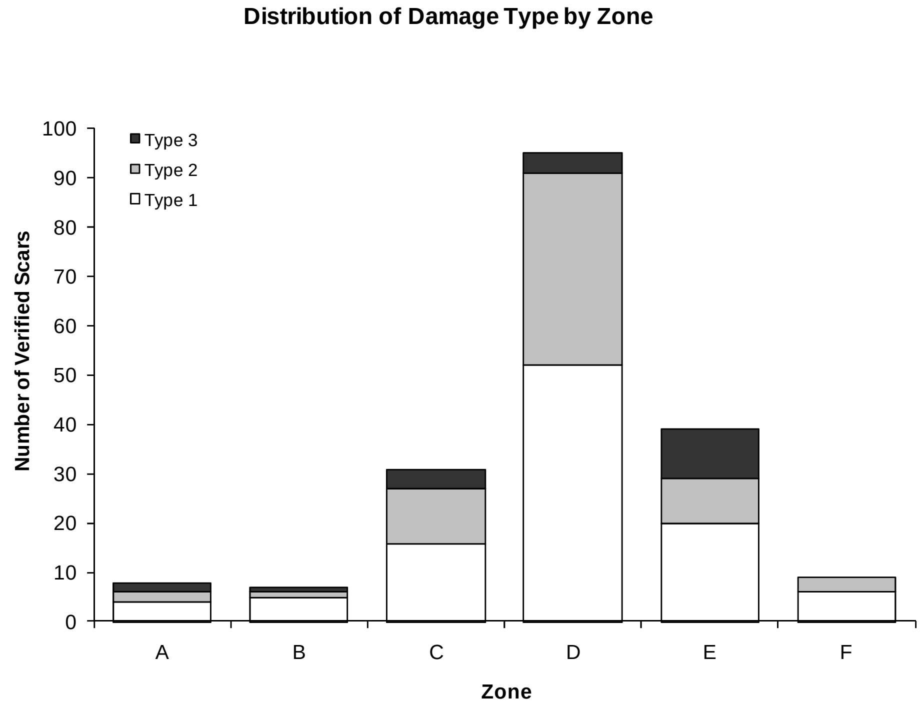


Figure 14. Depth distribution of verified propscars in 2010. Mean water depth (+/-SE) interpolated from point bathymetric data provided by Land and Sea Surveying Concepts, June 2007.



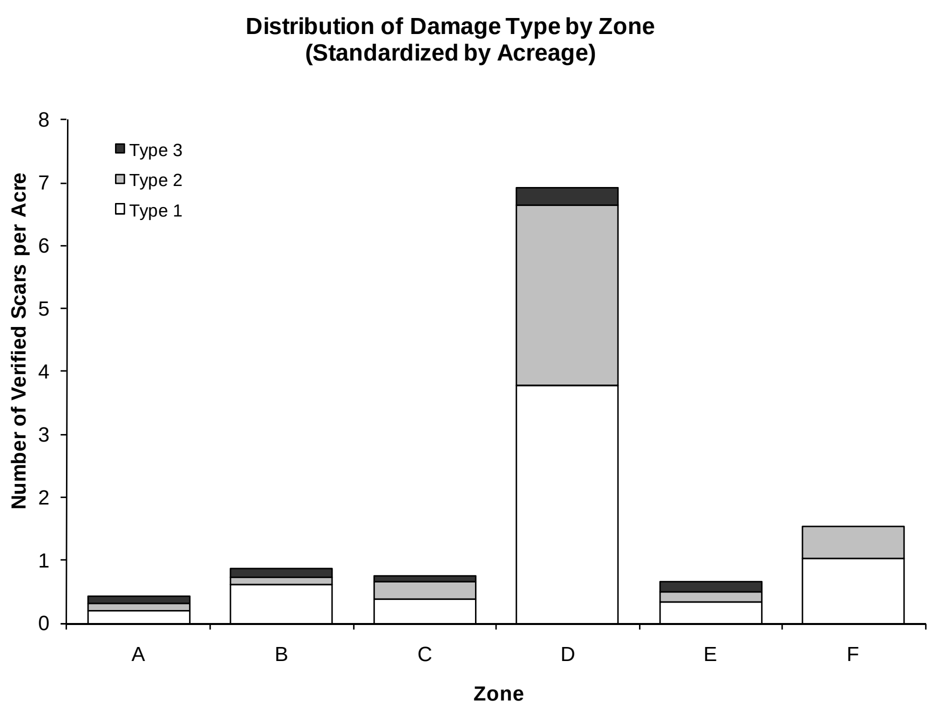


Figure 15. The distribution of damage type by mitigation zone (top) and standardized for area in 2010 (bottom).

Figure 16. Spatial distribution of anthropogenic damage by type (2010).

Figure 17. Scouring depth (cm) for Type III scarring observed within the mitigation area in 2010.

Figure 18. Scar length (m) for Type III scarring observed within the mitigation area in 2010.

A change analysis was conducted, comparing scar distributions between the 2007 (before), 2008 (1-yr post), 2009 (2-yr post), and 2010 (3-yr post) monitoring events, effectively a before and after evaluation of signage and channel influence on boater impacts to the shoal. One of the success criteria outlined in the ACOE (Special Condition 18, SAJ-2002-7868) and FDEP (Special Condition 23, File Number 05-264486-001) permits is the reduction of propscars on the flood shoal over time. Preliminary evidence suggested a net overall reduction in the total number of verified scars from 2007 (N=506) to 2009 (N=188) while the number of verified propscars was stable from 2009 to 2010 (N=189 in 2010). The decrease from 2007 to 2008 was due largely to a drop in Type I scarring, as overall numbers of Type II impacts rose and Type III impacts remained relatively stable (Figure 19). In contrast, the decrease in the number of verified propscars from 2008 to 2009 was due largely to a reduction in Type II and III scarring, as overall numbers of Type I impacts remained stable (Figure 19). The number of verified propscars was nearly identical for all propscar Type classes when comparing 2009 and 2010 data (Figure 19).

In order to better understand propscar trends over the course of this four-year study, we performed a Mann-Kendall test on the total number of verified propscars and the number of Type I, II and III propscars over time. While the total number of propscars have clearly decreased from 2007-2010, there is no statistically significant trend (Mann-Kendall test for trend, $p<0.05$) for any severity category or for total propscars. This is very likely due to the small sample size (n=4).

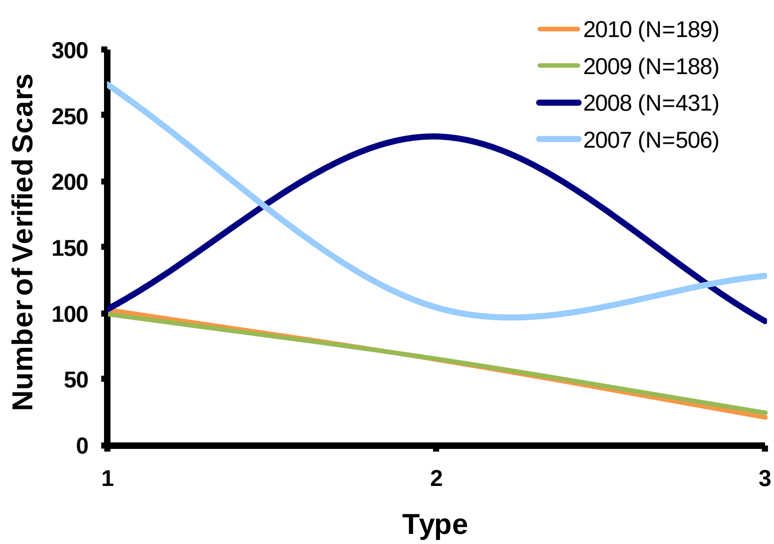


Figure 19. Number of verified scars by type for 2007, 2008, 2009, and 2010. N represents the total number of verified scars for each year.

The areas of greatest change in propscar occurrence from 2009 to 2010 were Zones D and E. Zone D experienced an increase in Type I and Type II scarring and a decrease in Type III scarring from 2009 to 2010. The inverse occurred in Zone E from 2009-2010, with decreases in Type I and II scarring and an increase in Type III scarring (Figure 20).

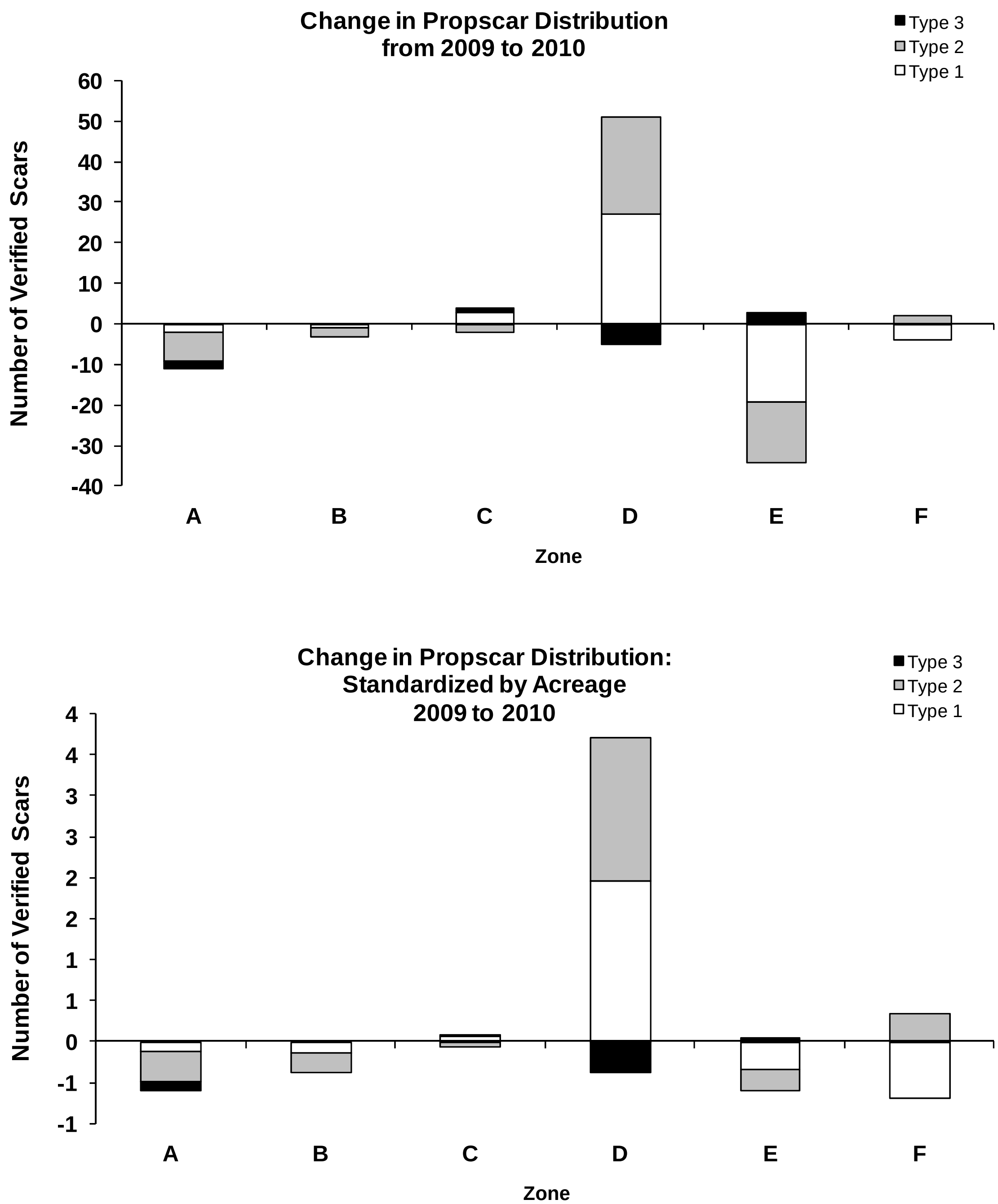
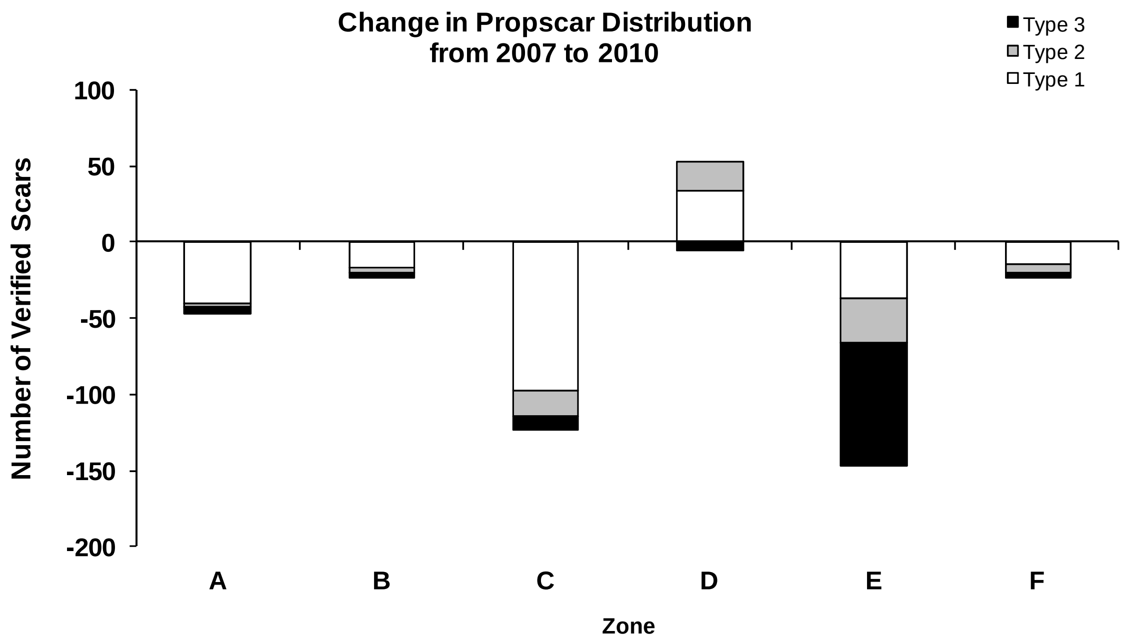


Figure 20. The change in propscar distribution by (top) mitigation zone and (bottom) after standardizing for area between the 2009 and 2010 monitoring events.

The areas of greatest change in propscar occurrence over a three-year period, from 2007 to 2010, were Zones C and E, with decreases in Type I and III scarring driving much of the overall pattern (Figure 21). It is also important to note that Zone D is the only zone showing an increase in propscarring from 2007 to 2010. Increases in Type I and II scarring are responsible for this pattern in Zone D while Type III scars decreased over the years. Despite the increase observed in Zone D, the overall reduction in scarring from 2007 to 2010 may be an indication that boaters are heeding the advice of the seagrass signage and finding that the channel does provide safe passage between the inlet and the ICW.



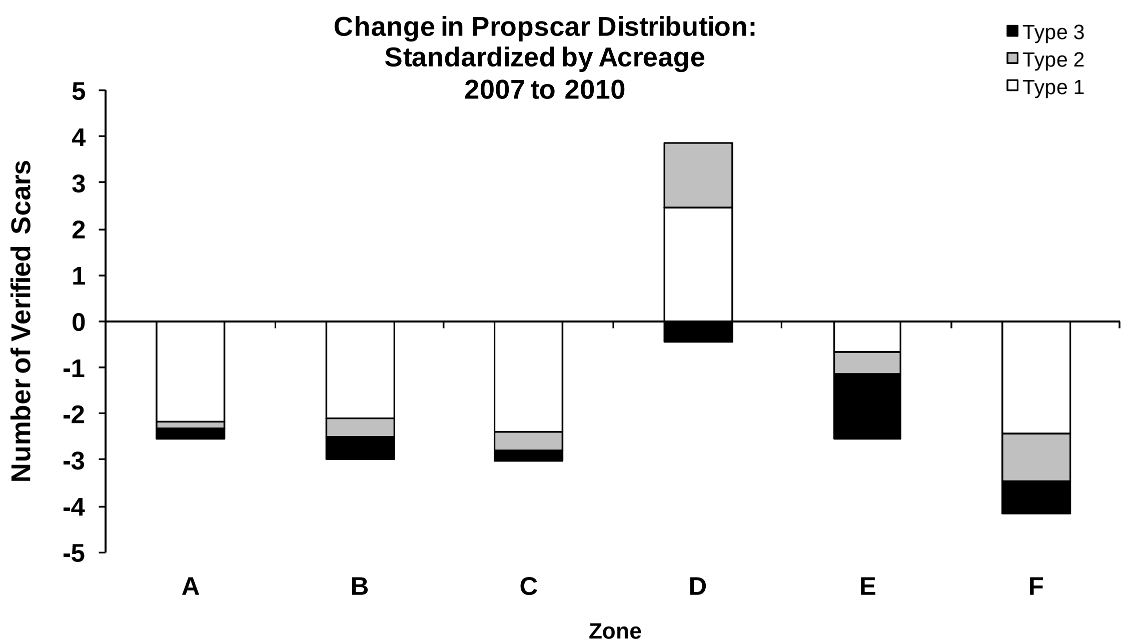


Figure 21. The change in propscar distribution by (top) mitigation zone and (bottom) after standardizing for area between the 2007 and 2010 monitoring events.

2.3.4. Spatial Statistical Analyses – Propscar Density and Hotspot Analysis

In an effort to more thoroughly describe the propscar dynamics on the shoal, PBS&J utilized geospatial tools and analysis techniques to calculate areas of highest propscarring incidence, or “hotspots”. Both kernel density and the Getis-Ord Gi* spatial statistic were implemented to spatially describe magnitude and clustering of propscar incidence among the mitigation zones. Conceptually, kernel density is practical for calculating a smooth, tapered surface describing the magnitude per unit area from point features that fall within a specific circular neighborhood (ESRI Resource Center 2010; Silverman 1986). The Getis-Ord Gi* spatial statistic compares each map feature to its neighboring features and computes a Z score indicating where features are highly clustered (ESRI Resource Center 2010). Z scores are measures of standard deviation and a Z score can indicate clustering of high or low values based on their deviation from the mean values. The actual score is computed by evaluating the local sum values of each feature and its neighboring features to the sum of all features. A high Z score indicates that the calculated local feature values are much different than the expected local sum values for that area and as such must be more intensely clustered. Moreover, a smaller (more negative) Z score would indicate a stronger clustering of low values. For this investigation, we were only interested in highly clustered high values (hotspots). In addition to the Z score, probability statistics (p-values) for each feature were calculated to determine whether to accept or reject the null hypothesis. For the purposes of this analysis the null hypothesis is defined as:

> H_0 = *The Sebastian Inlet mitigation protection zones do not exhibit any significant patterns of propscarring.*

2.3.4.1. Methodology

<u>*Propscar Density*</u>
To visualize the highest incidence of scarring among all mitigation zones, propscar density was calculated based on the kernel density methodology using ArcGIS Spatial Analyst 9.3.1. The output density grid was defined as having a cell size = 3.208 square map units (1 m^2). All other parameter inputs followed the ESRI default tool settings.

<u>*Hotspot Analysis*</u>
ESRI’s ArcGIS 9.3.1 spatial statistics toolset and a combination of geoprocessing tools were used to determine areas of significant clustering of seagrass propscars, if present. The initial step was to create a polygonal grid (10 m^2) across the entire study area in order to aggregate and quantify the number of scars over a regular area. The second step was to aggregate all verified propscars from 2007-2010 (N= 1314) together into one GIS dataset. Once the fishnet grid was created and propscars were aggregated, a spatial join was performed between the grid polygons and the aggregated scar occurrences in order to count the number of scars in each grid cell. These grid cells became the analysis features as described in the section above. The count of scars was used as the analysis field in the spatial statistic. In cases where the grid cells had a count = 0, those cells were clipped out prior to the analysis. The Getis-Ord Gi* spatial statistics tool in the Mapping Clusters toolset was utilized to quantify propscar hotspots. The formula for this analysis is as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j} \right)^2 \right]}{n-1}}}$$

where x_j (count) is the attribute value for feature *j* (propeller scarring), $w_{i,j}$ is the spatial weight between feature *i* and *j*, *n* is equal to the total number of features and:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \left(\bar{X}\right)^2}$$

Best practice recommendations guided the parameter inputs for this analysis. Since the source feature data were point based (aggregated to regular 10-m^2 grids) the Conceptualization of Spatial Relationships parameter value used was *fixed distance band*. This particular method is best suited for point data when calculating Getis-Ord Gi* statistics and provides a superior model interaction among features in the calculation (ESRI Resource Center 2010). For this analysis run, the Euclidean Distance method was implemented.

2.3.4.2. Results

<u>*Propscar Density*</u>

Results of the propscar density analysis revealed an overall decrease in propscar density throughout the mitigation area from 2007 to 2010. This decrease in propscarring may be due to the installation of "*Caution, Shallow Water, Seagrass Area*" signs in 2007. However, despite the overall decrease, an increase in the density of propscars is apparent in the southwestern portion of Zone D over the same time period (Figures 22 and 23).

<u>*Hotspot Analysis*</u>

A hotspot analysis was performed on 2007 to 2010 data to determine if propscar patterns were random in nature or if the observed clustering of propscars indicated a significant issue on the shoal. Our analysis results indicate there is a single region within the mitigation protection zones where significant (Z Score > 2.58 standard deviations from the mean and $p<0.05$) clustering is occurring. Figure 24 depicts the geospatial output from the spatial statistic. The color of the grid cells indicates the relative intensity/strength of clustering (hotspots). Note the significant (Z Score > 2.58 standard deviations from the mean and $p<0.05$) anthropogenic propscarring intensity in Zone D. In all other zones there were no significant patterns of propscar clustering.

Figure 22. Density of propscars within the mitigation area in 2007 (left) and 2008 (right).

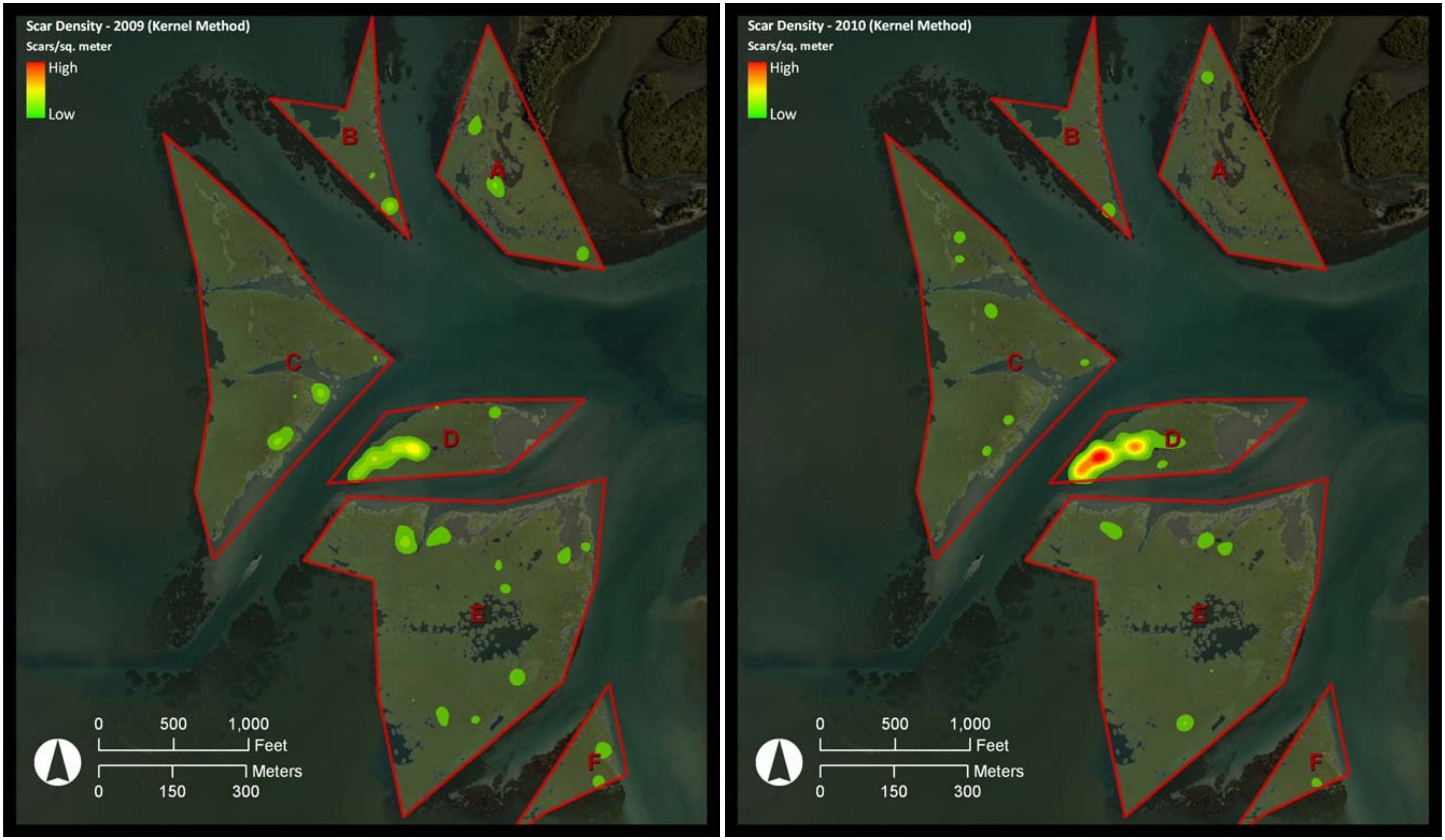


Figure 23. Density of propscars within the mitigation area in 2009 (left) and 2010 (right).

Figure 24. The map above depicts the analysis Gi* Z Score for each 10-m^2 grid in the mitigation protection zones as well as the 2010 photointerpreted and groundtruthed seagrass distribution. The color of the grid cell indicates the relative intensity/strength of clustering (hotspots). Note the significant (Z Score > 2.58 standard deviations from the mean and $p<0.05$) anthropogenic propscarring intensity in Zone D.

We can offer a tentative evaluation of the propscar distributions and densities mentioned above. The clustering of propscars in the western portion of Zone D may be due to the beaching practices common in that portion of the shoal. During the active restoration and annual monitoring events, numerous vessels were observed attempting to gain access to the area, which necessitates leaving the channel, potentially increasing the impact rates for all areas immediately adjacent to the recreational hotspot. This area also separates the unmarked “channel” between Zones D and E from the navigation channel connecting Sebastian Inlet to the ICW. It is possible that rather than going around the southwestern corner of Zone D, boaters are creating a short cut across Zone D to gain quicker access to the navigation channel and the inlet.

2.4. Active Restoration

2.4.1. Background

Seagrass Recovery, Inc. is a privately-held, coastal restoration company based out of Ruskin, Florida. Their patented (US Patent # 6,493,990B1) biodegradable cotton tube, or Sediment Tube®, was stipulated in the FDEP permit (No. 05-264486-001) as the sole means by which active restoration was to occur on the flood tidal shoal. As such, they were subcontracted by PBS&J in the spring of 2008 to provide, fill and install ~2,000 sediment tubes into pre-selected propeller-related scar features, including larger excavations hereafter referred to as ‘blow-outs’. The success criteria for the project are as follows (Special Condition 18, SAJ-2002-7868 and Special Condition 23, File Number 05-264486-001) and are discussed throughout *Section 2.4 ‘Active Restoration’*:

- Site bathymetry and tidal range are appropriate to support the targeted seagrass community;
- Nuisance species do not threaten the health of the seagrass beds;
- Physical monitoring of the prop-scar areas shows an increase in submerged aquatic vegetation (SAV);
- No new propscar damage is found;
- SAV is naturally growing without additional plantings;
- SAV coverage shall be similar to the adjacent seagrass beds;
- Based on the aerial photography (taken at the same time of year as the approved baseline photography), 80% of the unvegetated portions of a given mitigation site shall show seagrass coverage; and
- Three consecutive years of success have been achieved.

Site bathymetry and tidal range are only two of many factors controlling seagrass distribution within the mitigation zones. The active restoration efforts were focused in Zone E in May 2008. The coverage of seagrass within Zone E in 2008, calculated from aerial photography and verified using groundtruthing exercises, was ~48 acres and encompassed ~84% of the mitigation zone. In 2009 and 2010, seagrass coverage was estimated at ~47 acres (~81% of the mitigation zone) and ~46 acres (~79% of the mitigation zone), respectively. Over the past three years, the coverage of seagrass within Zone E has been relatively constant, demonstrating that the current environmental conditions support the seagrass community. Nuisance species have not been observed within the restoration areas on the flood tidal shoal and therefore do not threaten the health of the seagrass community.

2.4.2. Methodology

In May 2008, 2,031 sediment tubes were successfully installed in 32 documented features, including 10 propscars and 22 blow-outs (Figure 25). The number of tubes per feature varied from 2 to 869 tubes with a total restored area of 0.096 acres (propscars, 0.0132 acres; blow-outs, 0.0829 acres). The purpose and utility of the sediment tubes toward the restoration objectives were three-fold: (1) to fill scar features of significant scour to grade; (2) to deliver sediment of a grain size consistent with that of the surrounding substrate; and (3) to prevent additional erosion induced by turbulent water flow (see the *Year 1 Monitoring* report for further information). The 2010 groundtruthing event for the aerial image analysis occurred on October 11-15, 2010, 29 months after installation of the sediment tubes. During this time all 32 of the repaired locations were visited and a quick qualitative assessment was conducted to track their progress. Three blow-outs that had not been repaired in May 2008 were also visited in 2010 in order to compare recovery rates between those features that had been repaired versus those that remained untreated.

2.4.3. Results

As of mid-October 2010, 22 of the 32 repaired features (all ten of the repaired propscars and 12 repaired blow-outs) exhibited vegetative re-growth of adjacent seagrasses into at least a portion of the scar (Figure 26). All repaired propscars had completely recovered and satisfied the success criteria described within the ACOE (Special Condition 18, SAJ-2002-7868) and FDEP (Special Condition 23, File Number 05-264486-001) permits. Physical monitoring of the repaired propscars showed an increase in SAV within the scar features from 2008 to 2010. In October 2010, no signs of the original propscars were observed and SAV coverage within the repaired propscars was similar to the surrounding seagrass bed. The seagrass growth observed within the propscars was solely due to natural revegetation made possible by the installation of sediment tubes into the propscars. Seagrass transplantation was not necessary. One of the success criteria stipulated in the FDEP permit requires that 80% of the un-vegetated portions show seagrass coverage. In October 2010, 100% of the repaired propscars using sediment tube technology exhibited vegetative re-growth. Due to complete recovery, these repaired propscars will no longer be monitored during future monitoring events.

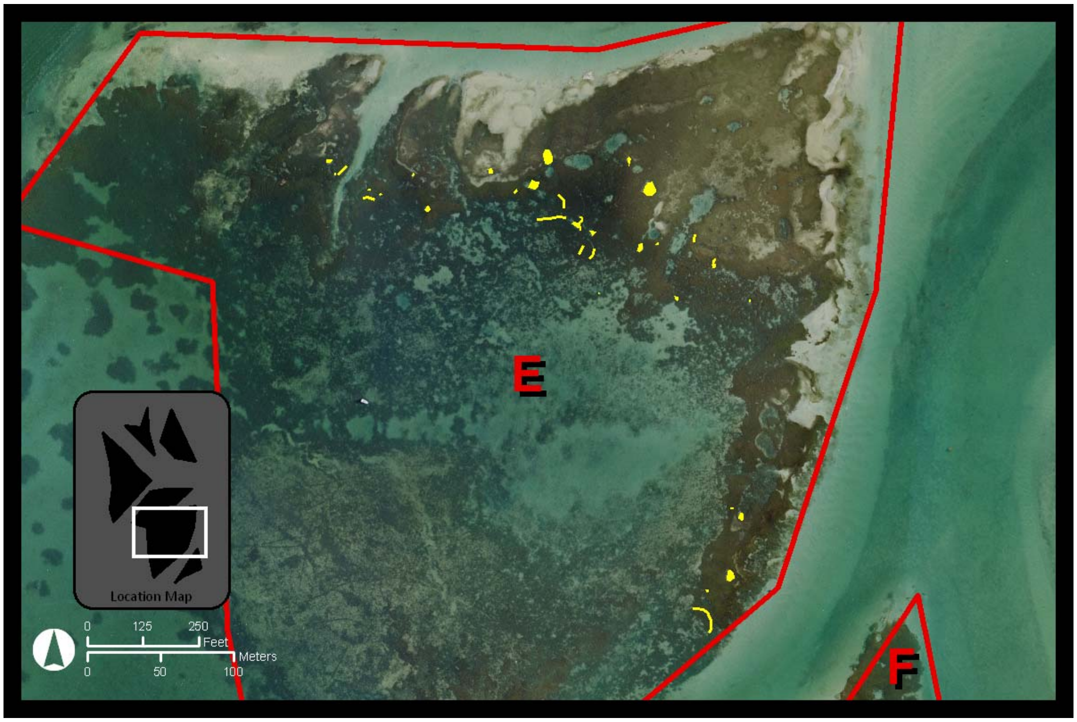


Figure 25. Location of the 32 scar features (10 propscar, 22 blow-out) repaired using sediment tubes during May of 2008. Sites marked in yellow. Aerial photo from June 2008.

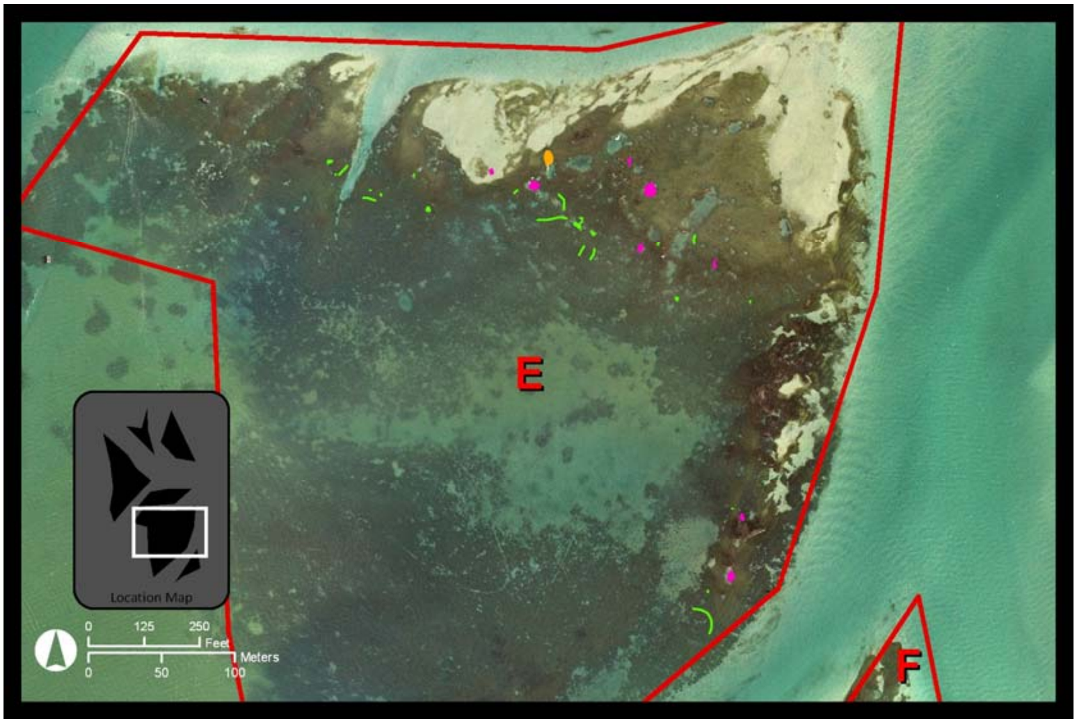


Figure 26. Map showing the locations of repaired propscar and blow-out features. Recovered features are depicted as green, unchanged features appear purple, and the unknown status of one feature appears orange. Aerial photo from August 2010.

Seagrass was observed within twelve of the 22 repaired blow-out features (Figure 26). At six of these 12 sites the blowout feature was no longer visible and seagrass was observed throughout. At these six locations the success criteria outlined in the ACOE and FDEP permits were met. Physical monitoring showed an increase in SAV; SAV was naturally growing without seagrass transplantation; and the SAV coverage within the ‘blow-out’ feature was similar to the adjacent seagrass bed. The other six locations contained sparse seagrass migrating into the repaired blow-out from the edge. Despite the seagrass growth observed at twelve of the repaired blow-out sites, nine sites continued to be void of seagrasses in October 2010 (Figure 26). Drift algae and detrital material had settled into one of the blow-outs which may have prevented the growth of seagrasses. No additional scour was recorded at these nine locations and seagrasses were observed along the perimeter of the blow-outs, indicating potential recovery in the future. Due to ambiguity in GIS dataset geometry, we cannot be certain if one of the repaired blow-out sites exhibited recovery or not (Figure 26, feature depicted as orange). One of the success criteria outlined in the FDEP permit requires that 80% of the un-vegetated portions show seagrass coverage. As of October 2010 seagrass coverage was observed in 12 of the 22 repaired blow-outs or ~55%. Future monitoring events will be conducted annually to update their progress and to provide continued assessment of seagrass encroachment over time.

Three blow-outs that had not been repaired in May 2008 were also visited in 2010 in order to compare recovery rates between those features that had been repaired versus those that remained untreated. In 2010, one of the three blow-outs that had not been repaired in May 2008 continued to be scoured and void of seagrasses while the other two blow-outs had sparse, patchy seagrass growing into a portion of the feature.

2.4.4. Change Analysis (2009 - 2010)

There appeared to be an increase in the number of repaired sites (N=32) showing recovery from 2009 to 2010 (2009: 20 sites; 2010: 22 sites). In both 2009 and 2010 all ten of the repaired propscars exhibited recovery and there was no sign of the original propscar. In 2009, ten of the 22 repaired blowouts showed vegetative re-growth while 12 exhibited some stage of recovery in 2010. This represents an increase of two sites from 2009 to 2010. It appears that the untreated blow-outs are also exhibiting vegetative re-growth. In 2009, only one of the three untreated blow-outs showed vegetative re-growth while two contained seagrass in 2010. This represents an increase in one site from 2009 to 2010.

2.5. Seagrass Transplantation: Year-Three Monitoring

On March 27 and 28, 2007, PBS&J biologists identified a total of 65 propscars within the vicinity of the National Marine Fisheries Service’s (NMFS) Critical Habitat Areas, and on a tidally exposed shoal to the north of the Inlet (i.e., Zone A). The latter region was chosen to augment the proposed planting effort for two reasons: (1) it is subjected to less flow with each tidal cycle and (2) it contained more scarring than the targeted NMF Critical Habitat Areas. Of these scars, 58 were deemed repairable to some degree and marked with a handheld GPS. Most, if not all of these scars exhibited clear signs of natural recovery. Sediment scouring was rarely observed to exceed 5 cm and only five scars were associated with any discernable blow-out.

Between April 24 and May 16, 2007, planting material was manually removed from the proposed channel with consumer grade pitch forks and shovels by PBS&J divers on SCUBA. The propscars previously marked using handheld GPS (Garmin) were located. Only those portions of the propscars not containing rhizomes were planted using a modified bare-root method. To minimize disturbance to the sediment-water interface, a flat-bladed trowel was inserted ~10 cm into the substrate and carefully angled back 45 degrees. A planting unit (PU) measuring 10-cm in diameter was slid along the trowel blade until the rhizomes were below the sediment water interface. The trowel was then slowly removed and the sediment pressed downward. A single sod staple was placed through the rhizomes and pressed flush with the surface. Using this methodology, PBS&J biologists successfully transplanted 458 planting units (179 PU of *Halodule wrightii*, 279 PU of *Syringodium filiforme*) into 41 propscars.

During October of 2010, a qualitative, year-three monitoring of the repaired features was conducted. Using Trimble Geo-XT handheld DGPS units, we navigated to those transplanted propscars that were found in 2009 (N=2; also accidentally visited two sites that were not previously found in 2009) and searched the area for a rubber ‘cow’ tag and 12-inch galvanized steel stake that had been used to number and permanently mark each scar. Despite the use of extremely accurate GPS, we were unable to locate the two ‘cow’ tags. At both locations the original propscar was no longer visible and seagrass was observed throughout.

The degree to which the PU’s of 2007 played a direct role in this remains undetermined. Very few planting stakes were found in 2008, even less in 2009, and none were found in 2010. In cases where PU species composition differed from the adjacent bed, only the adjacent species was observed within the previous scar, indicating PU death and natural vegetative re-growth. The speed with which this recovery occurred (within one year) points heavily toward the natural resilience of the shoal and can be seen as a general indicator of seagrass health within the mitigation zone.

3.0 Indian River Lagoon Main Relief Canal, Vero Beach, Florida

3.1. Fixed Seagrass Transects

3.1.1. Background

The Indian River Farms Water Control District (IRFWCD) canal drains over 51,000 acres of land into the Indian River Lagoon (IRL). All stormwater runoff and groundwater seepage collected by the IRFWCD's ~300 miles of canals is discharged into the IRL through three large canals – North, Main and South Relief Canals. The Main Relief Canal is the largest, releasing greater than half of the total amount of water. The state of the art stormwater control structure located at the Main Relief Canal removes huge volumes of trash, debris, vegetative matter, and sediment (Figure 27). Every year it removes over 50,000 lb. of nitrogen and phosphorus and ~906,000 lb. of sediment or total suspended solids (Turning the Tide 2008). To date at least 300 cubic yards of sediment have been removed from the system as a direct result of the new stormwater control structure (Personal communication, Keith McCully, Indian River County).

Figure 27. Photographs of the Main Relief Canal Stormwater Treatment Facility. The self cleaning screens capture debris and vegetative material and dump it onto a conveyor that discharges the material into dumpsters. Photos courtesy of Indian River County (Turning the Tide 2008).

3.1.2. Methodology

Between May 28, 2007 and July 27, 2010, PBS&J biologists established and seven times (3 winter, 4 summer) monitored the SJRWMD fixed seagrass transect No. 51 plus nine (9) additional transects in the vicinity of the Main Relief Canal Outfall (Vero Beach, Florida). These 10 transects (total) included locations both north and south of the outfall and were specifically sited to quantify future potential changes in seagrass occurrence following the activation of the Indian River County Main Relief Canal Stormwater Treatment Facility.

Methodology conformed to those of the SJRWMD and all data were provided to the SJRWMD for inclusion in their basin-wide seagrass monitoring program. Based on discussions with Dr. Robert Virnstein and field training/calibration provided by Lauren Hall (SJRWMD), the following metrics were selected from the full monitoring protocol to facilitate a faster field visit while still providing the required information to the SJRWMD: percent cover by species, visual percent cover by species, canopy height by species, edge of bed, and furthest extent of seagrass.

All finalized transect locations met the following criteria:

- Sites representing locations north and south of the outfall;
- Sites with potential habitat extending beyond the current edge of seagrass (i.e., sites capable of showing seagrass expansion);
- Sites containing at least some portion of moderate to high density seagrass; and
- Final approval of the SJRWMD, FDEP.

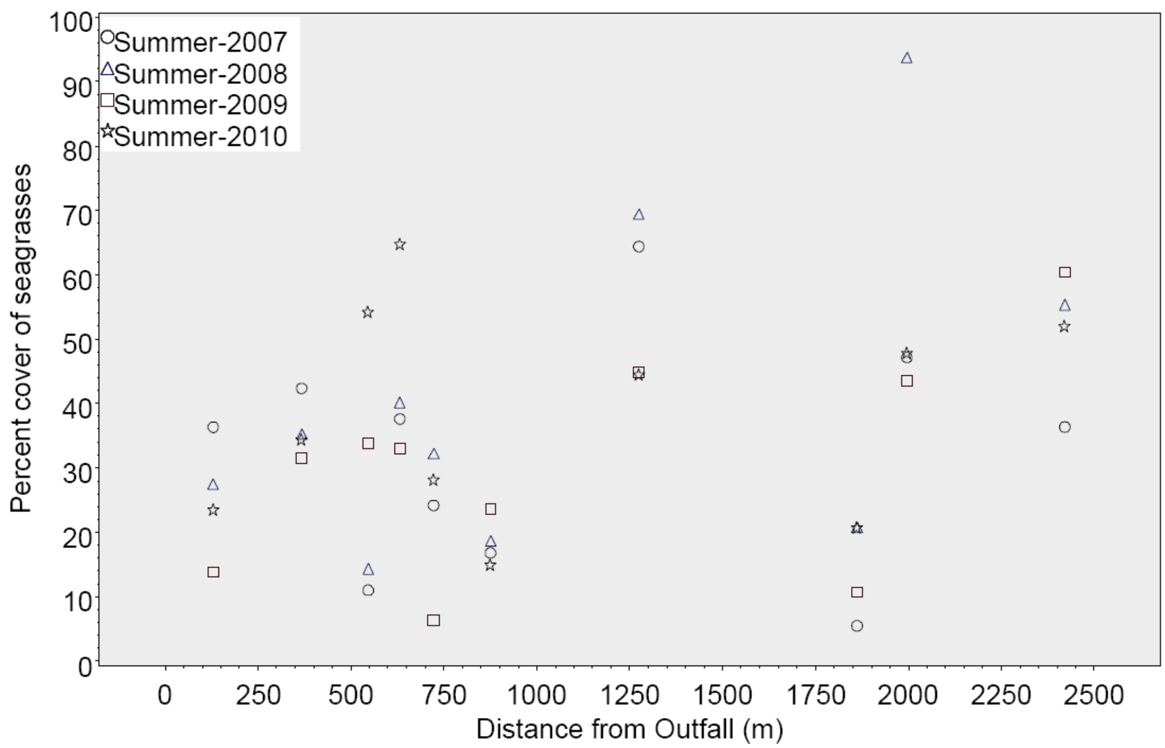
3.1.3. Results

The stormwater control structure was activated in mid-July of 2008. Project data includes baseline conditions (2007 and 2008) and two years of post treatment monitoring (2009 and 2010) results for seagrass coverage within the study area. The 2008 monitoring event occurred shortly after activation of the stormwater control structure. As a result, the 2008 data were considered as “pretreatment”. Seagrass monitoring continued in 2010, allowing for the comparison of baseline conditions (2007 and 2008) with post treatment conditions (2009 and 2010). Statistical analyses were performed to assess the putative influences of particulate matter removal on the density and extent of seagrasses within the vicinity of the Vero Beach Main Relief Canal.

A Kruskal-Wallis test was performed to determine if there were any significant differences in the percent cover of seagrass (total visual cover) or the location of the edge of the seagrass bed before and after the stormwater control structure was turned on. Results showed that there was no significant difference in the percent cover of seagrasses (summer: $p=0.57$; winter: $p=0.09$) or the location of the edge of bed (summer: $p=0.75$; winter: $p=0.80$) interannually, including years before and after the stormwater control structure was activated.

Regression analyses (SAS, the GLM Procedure) were performed to test the relationship between distance from the outfall and a variety of seagrass metrics. The data indicate a slight positive trend in both summer and winter when comparing the percent cover of seagrass to distance from the outfall (Figure 28) and a strong negative trend between the edge of seagrass bed and distance from the outfall (Figure 29). The regression analysis showed no significant relationship between the percent cover of seagrass and distance from the outfall. However, there was a statistically significant inverse, linear relationship between the edge of seagrass bed and distance from the stormwater outfall (regression analysis via SAS Proc GLM) with all stations included (Edge=f(Log(Distance)), $p<0.001$, $R^2=0.26$); however removal of transects 4 and 51, on the basis that they are substantially shorter than all other transects and thus not properly comparable, yielded a result (Edge=f(Distance)) with $p<0.001$ and $R^2=0.75$. With this data treatment the value of R^2 increased from 0.26 to 0.75. A R^2 value of 0.75 infers that 75% of the variation in edge of seagrass bed can be explained by distance from outfall. Additional analyses were performed with water depth data to determine possible explanations/mechanisms for this inverse, linear relationship. If suspended sediments are reducing water clarity which in turn reduces seagrass growth, then it would be expected that seagrasses should grow in deeper waters further from the outfall. There is no statistically significant ($p<0.05$) linear relationship between depth at edge of seagrass bed and distance from outfall in the untransformed or natural log transformed data.

Figure 30 presents the location and depth profiles of all ten transects surveyed in the vicinity of the Main Relief Canal Outfall. General trends regarding seasonal and inter-year variance were observed along these transects. These include, but were not limited to: (1) the occurrence of all seven locally found seagrass species, (2) the decrease in the percent cover of seagrass at all transects when comparing summer to winter (Figures 31 and 32), (3) the pronounced deepwater, winter pulse of *Halophila decipiens* (Figures 33 and 34), and (4) retraction of the edge of bed during the winter (with the exception of Transect 9; Figure 35). Time series plots of seagrass distribution for each transect are provided in Figures 36 and 37. No major trends were observed in the percent cover of seagrass before and after the stormwater control structure was activated.



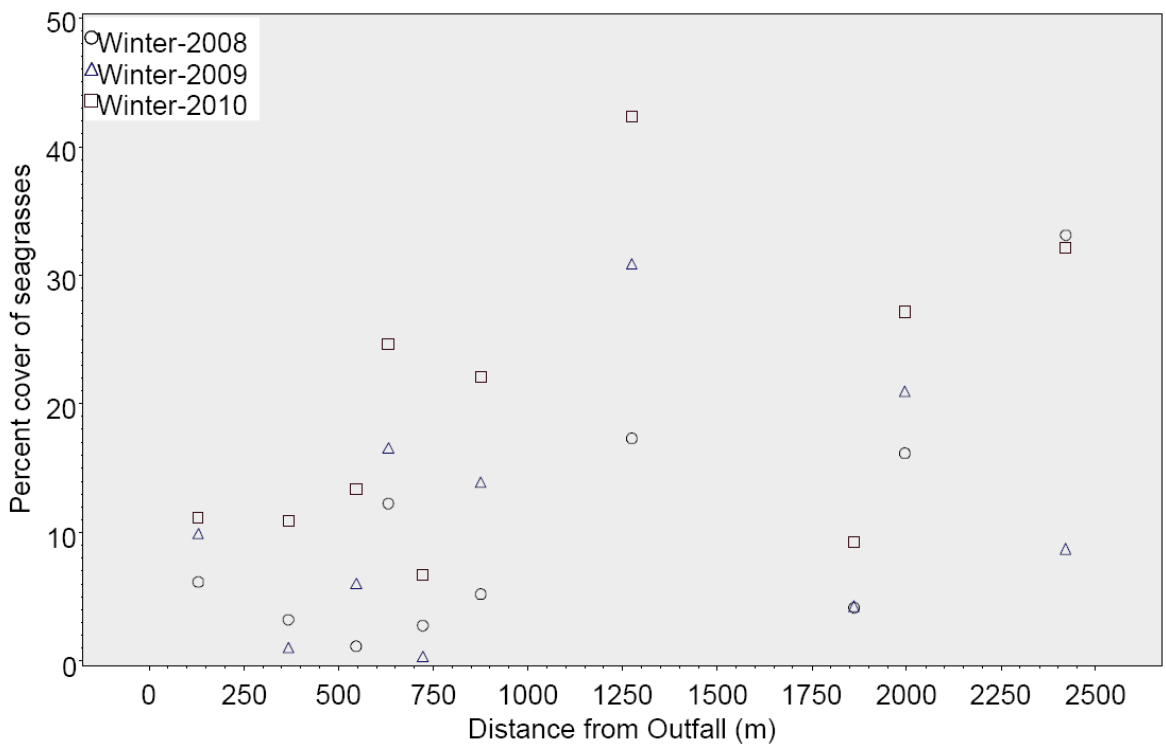
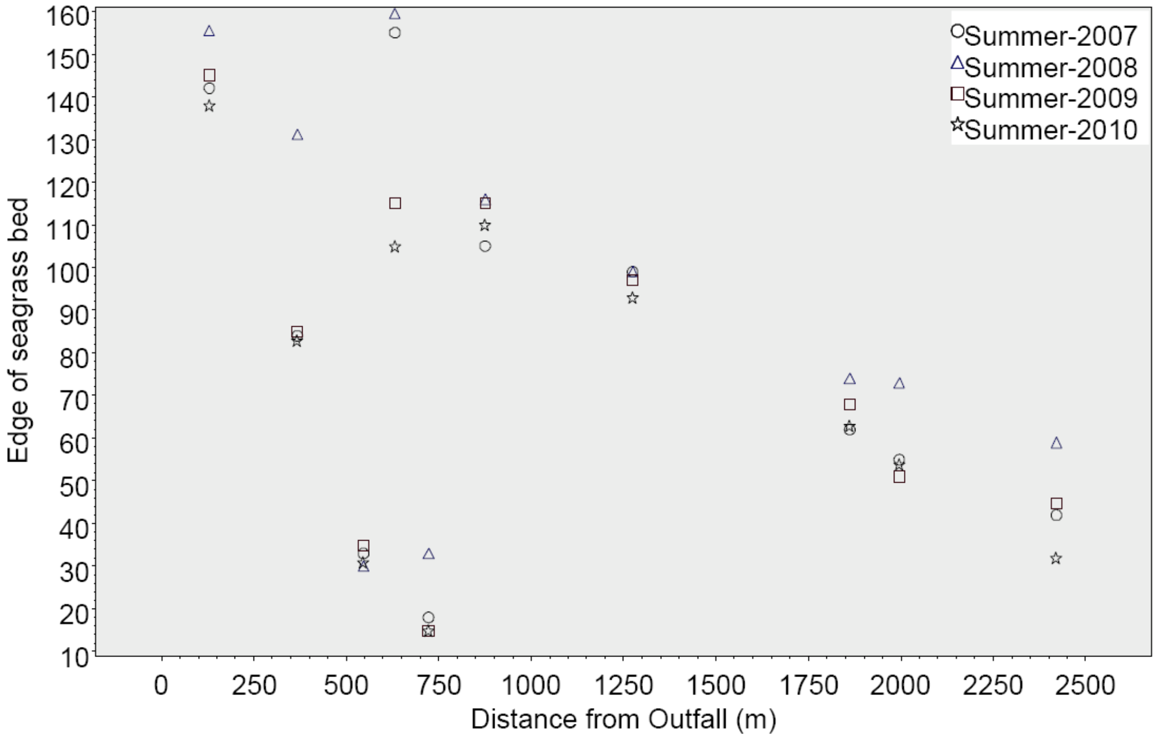


Figure 28. Percent cover of seagrass (total visual cover) versus distance from stormwater outfall (m) for PBS&J Transects 1-9 and SJRWMD 51 in the summer of 2007, 2008, 2009, and 2010 (top) and winter of 2008, 2009, and 2010 (bottom).



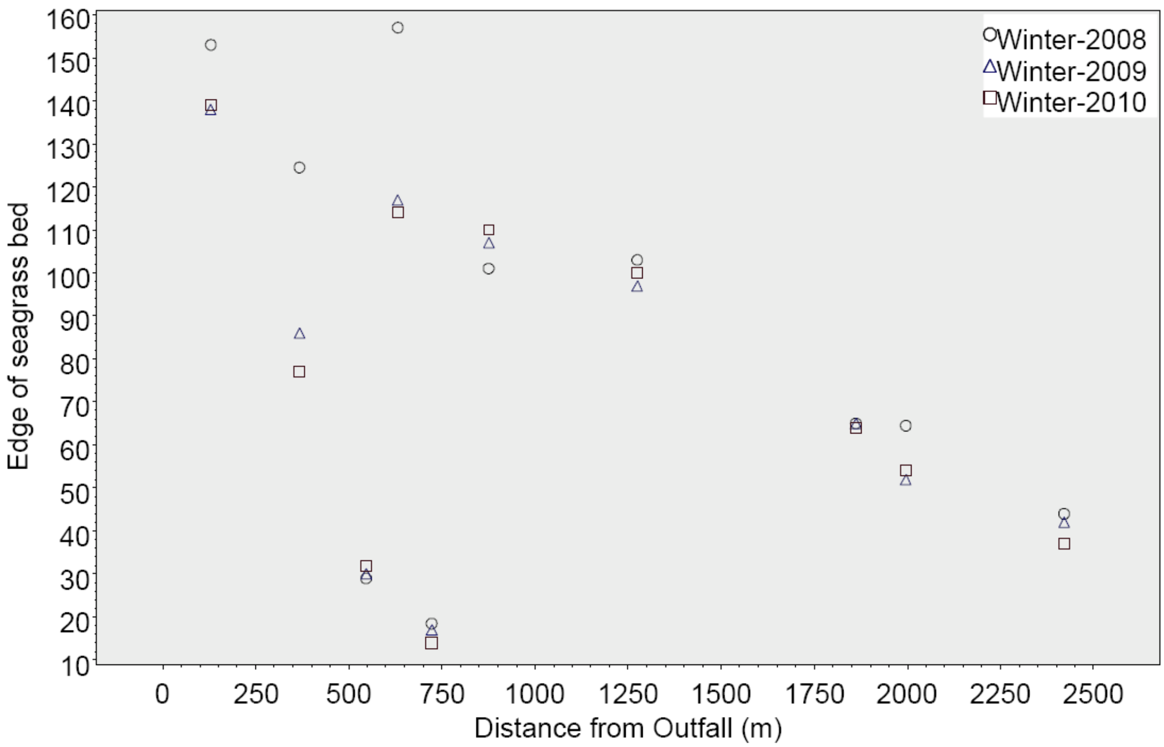


Figure 29. Edge of seagrass bed (m) versus the distance from the stormwater outfall (m) for PBS&J Transects 1-9 and SJRWMD 51 in the summer of 2007, 2008, 2009, and 2010 (top) and winter of 2008, 2009, and 2010 (bottom).

Vero Beach Transects: Depth Profiles

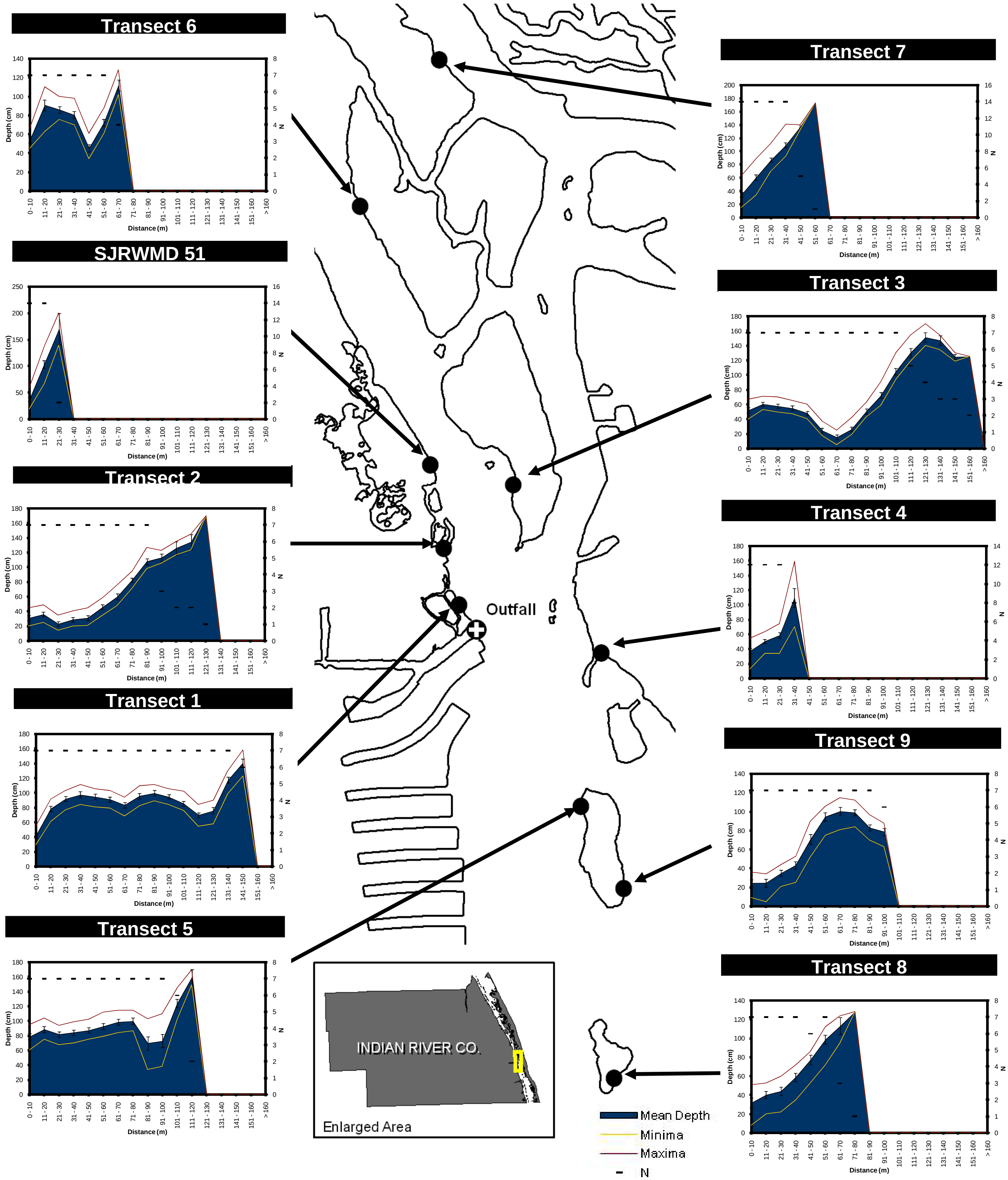


Figure 30. Location and depth profiles of the fixed seagrass transects established and monitored by PBS&J as part of the Indian River County Regional Stormwater Treatment Project, 2007-2010.

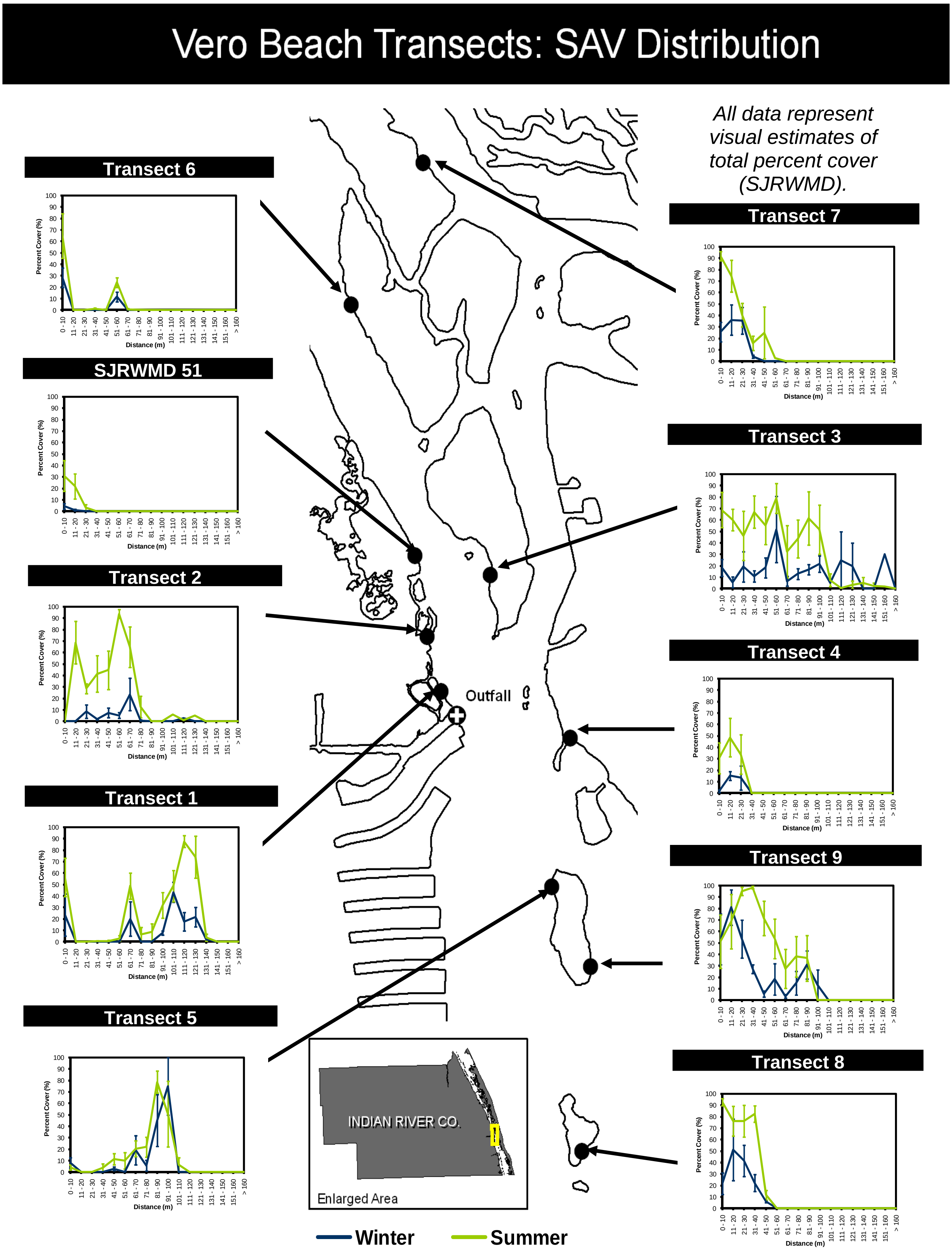


Figure 31. Seasonal distribution of seagrass cover by distance from shore for each of the fixed transects monitored in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL. Data collected May 2007, February 2008, July 2008, February 2009, July 2009, March 2010, and July 2010 (Summer, N=4; Winter, N=3).

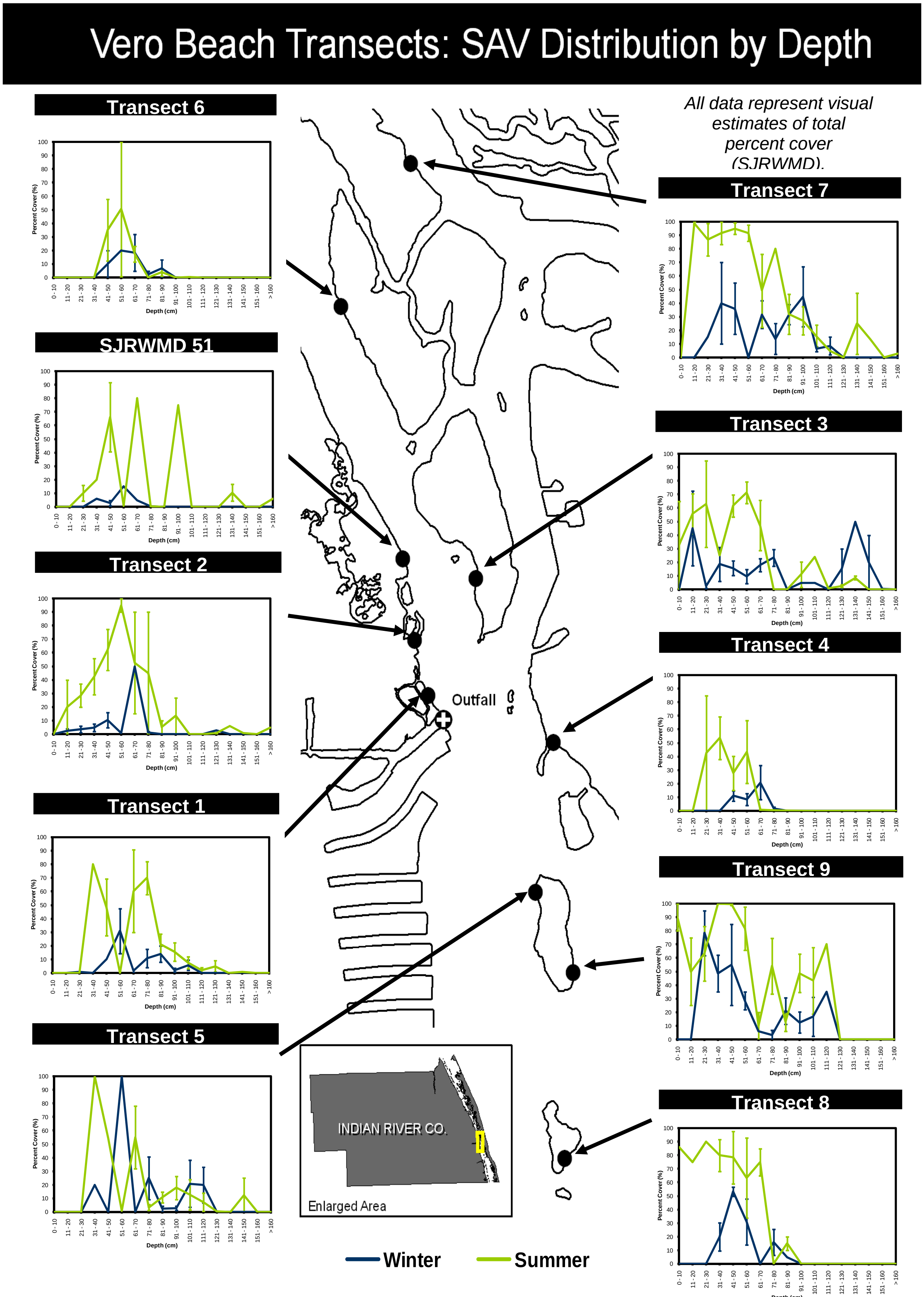


Figure 32. Seasonal distribution of seagrass cover by depth for each of the fixed transects monitored in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL. Data collected May 2007, February 2008, July 2008, February 2009, July 2009, March 2010, and July 2010 (Summer, N=4; Winter, N=3).

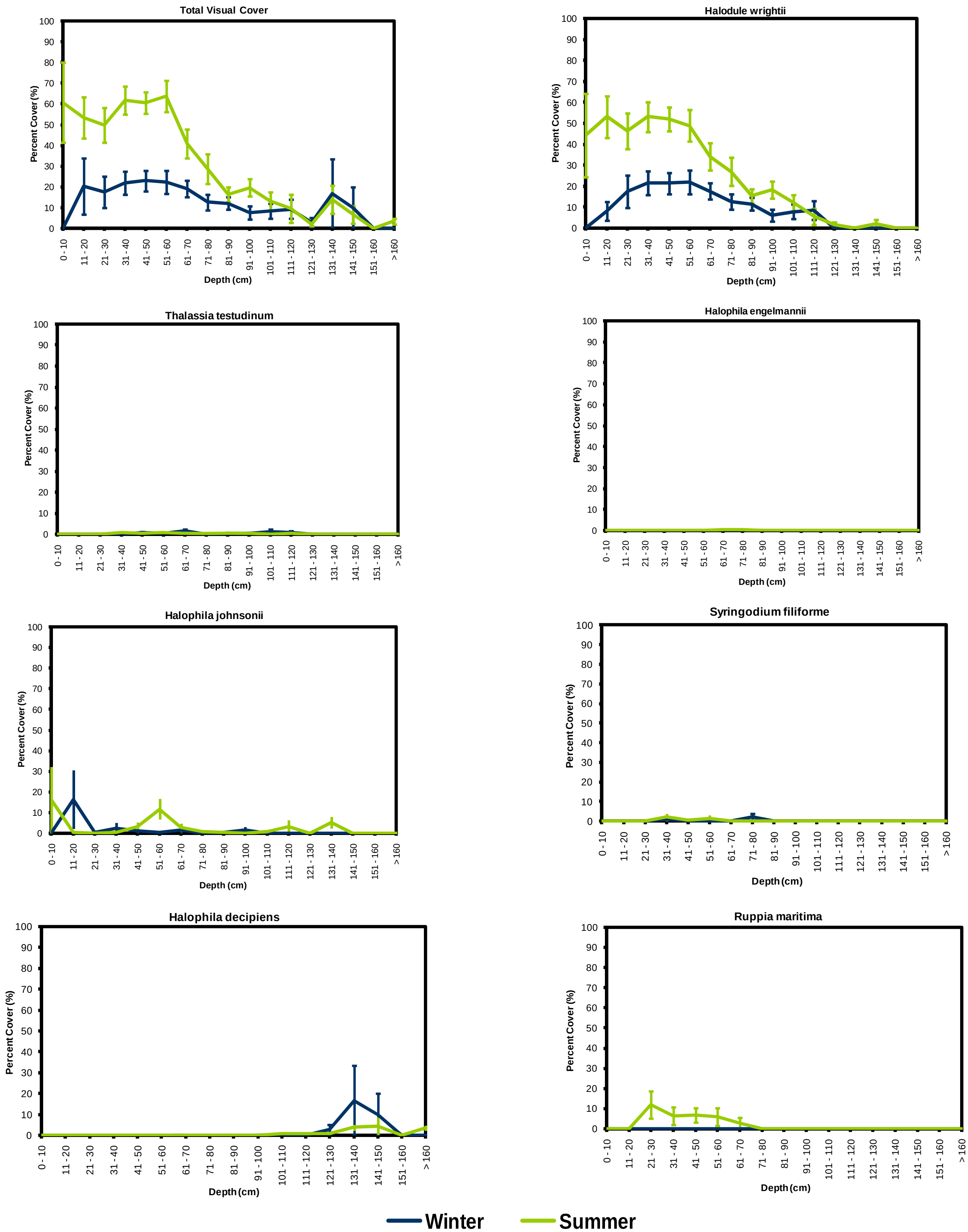


Figure 33. Visual percent cover of total seagrass, *Halodule wrightii*, *Thalassia testudinum*, *Halophila engelmannii*, *Halophila johnsonii*, *Syringodium filiforme*, *Halophila decipiens*, and *Ruppia maritima* by depth for all fixed transects monitored in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL. Data collected May 2007, February 2008, July 2008, February 2009, July 2009, March 2010, and July 2010 (Summer, N=4; Winter, N=3).

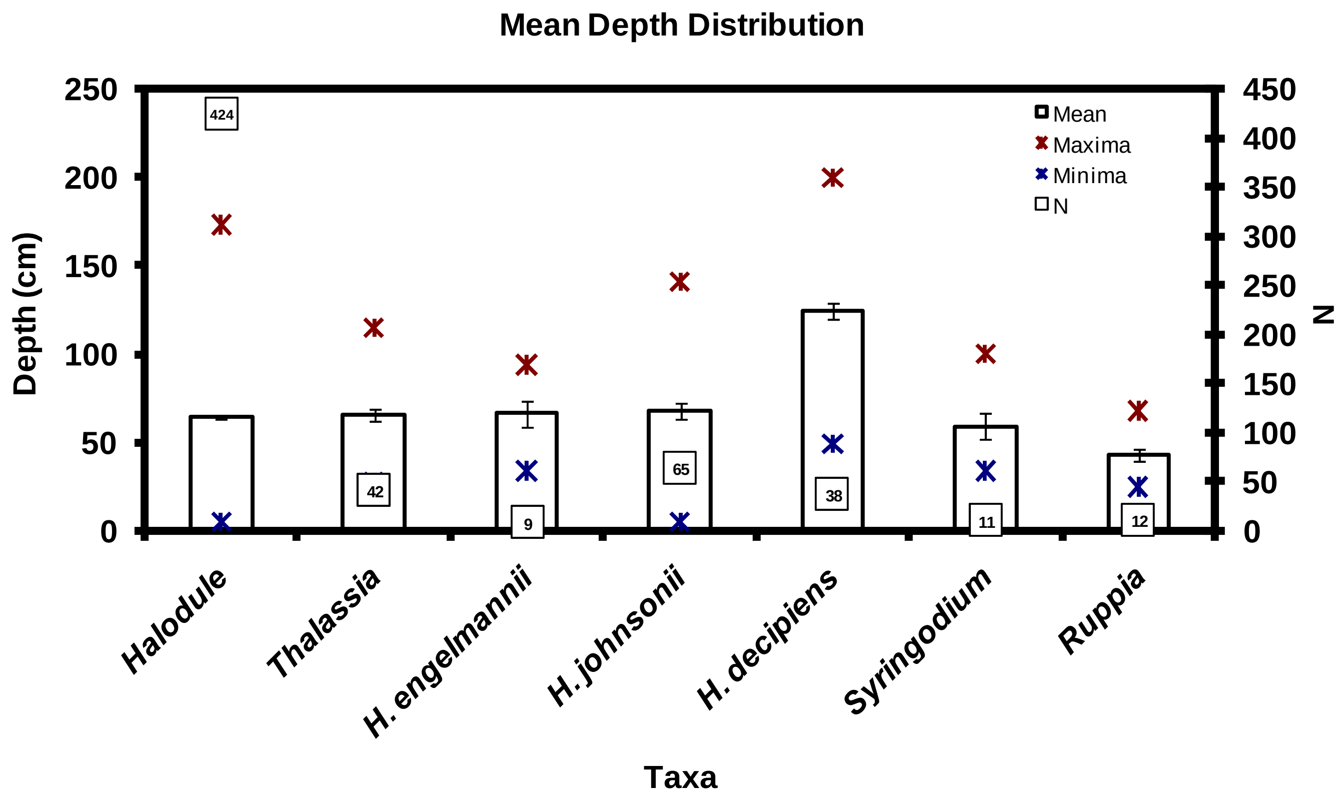


Figure 34. Mean (+/- SE) depth distribution of species as averaged across all transects. Occurrence of species determined by nonzero percent cover estimated with m^2 quadrats. N-values depicted within boxes (alt-axis). Data collected May 2007, February 2008, July 2008, February 2009, July 2009, March 2010, and July 2010 (Summer, N=4; Winter, N=3).

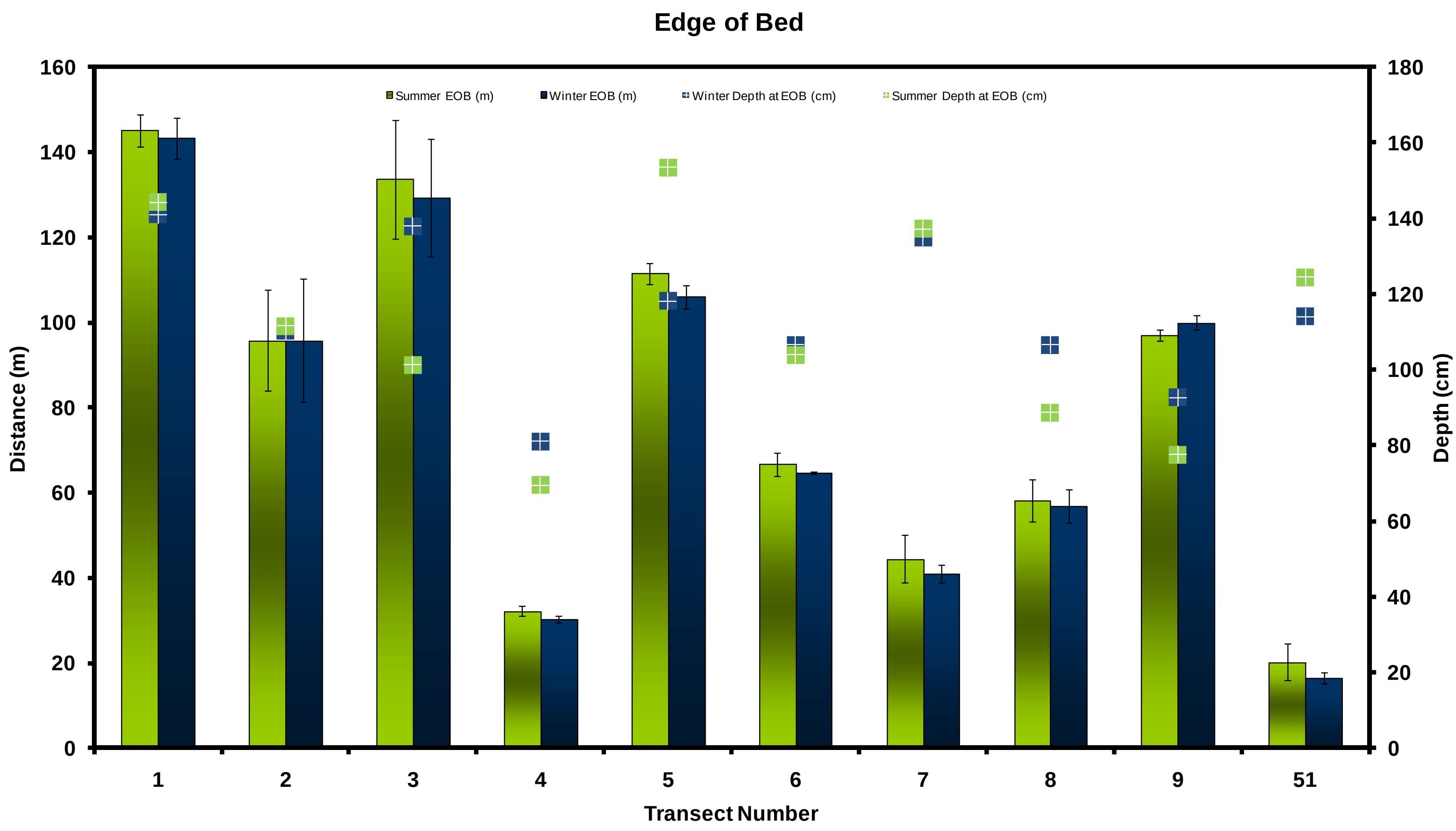


Figure 35. Edge of bed (m) and depth (cm) at edge of bed observed during summer (N=4) and winter (N=3) monitoring of fixed seagrass transects monitored in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL. Data collected May 2007, February 2008, July 2008, February 2009, July 2009, March 2010, and July 2010.

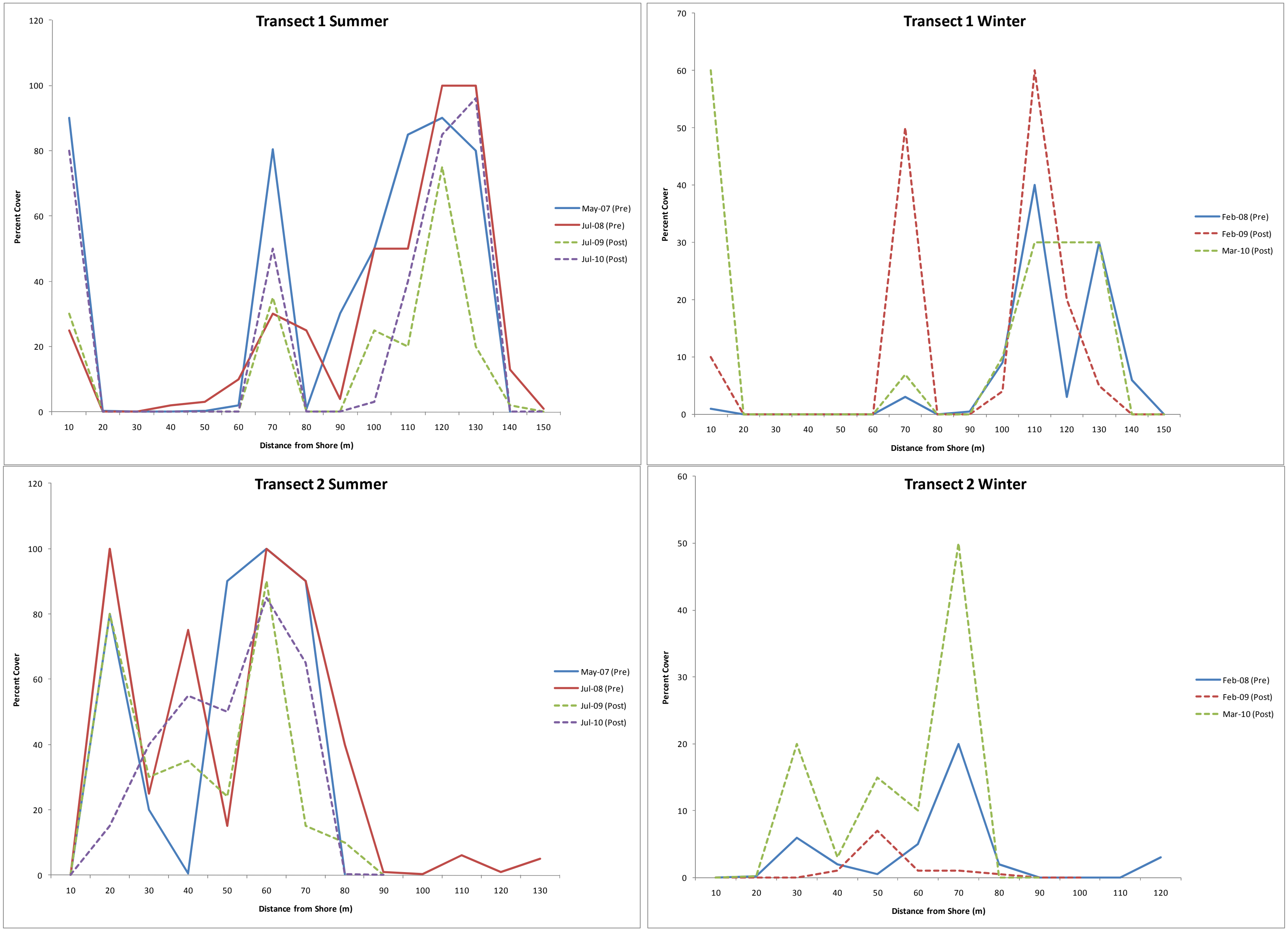


Figure 36. Time series plots (2007-2010) depicting visual percent cover of total seagrass by distance from shore for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).

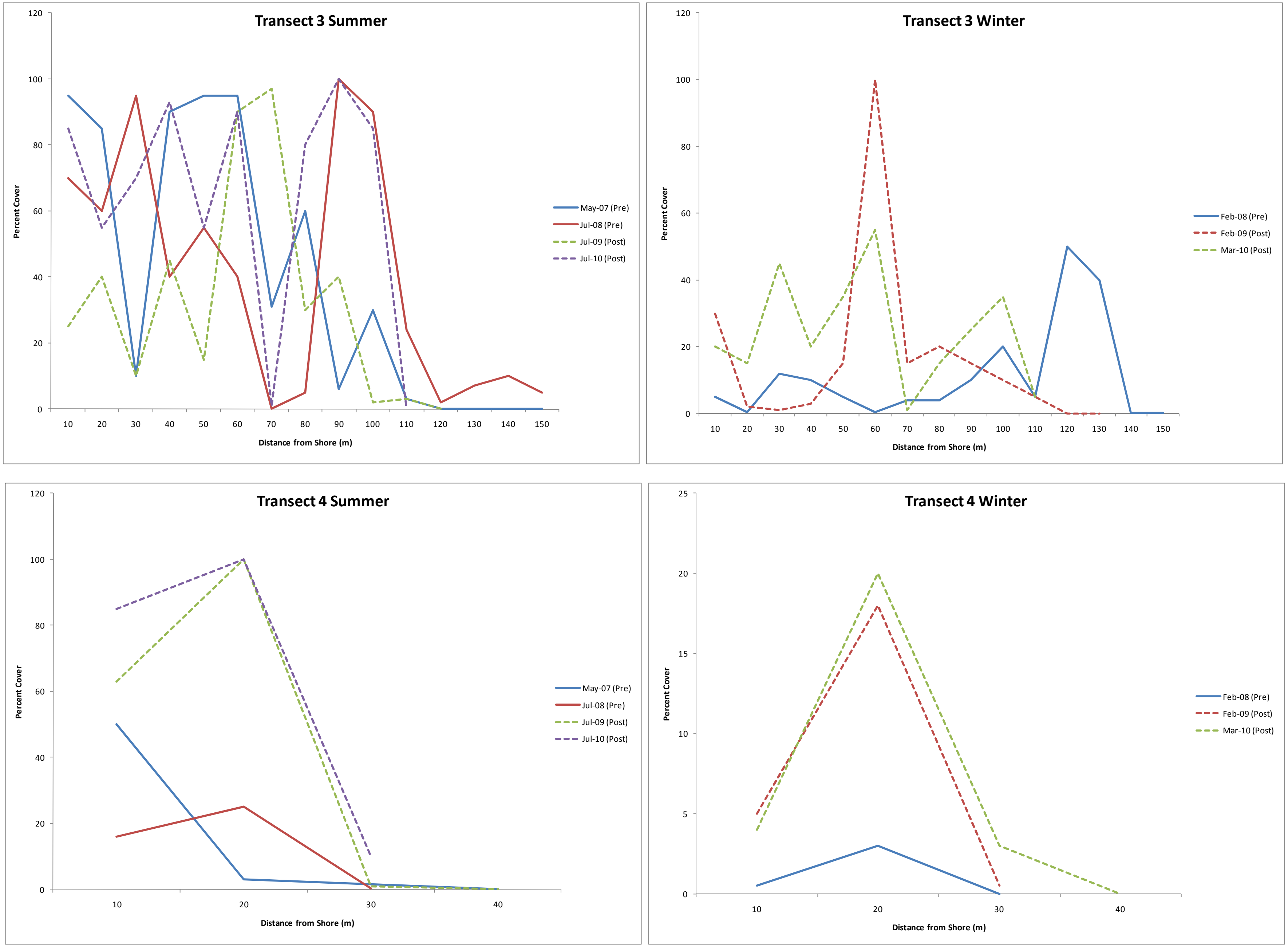
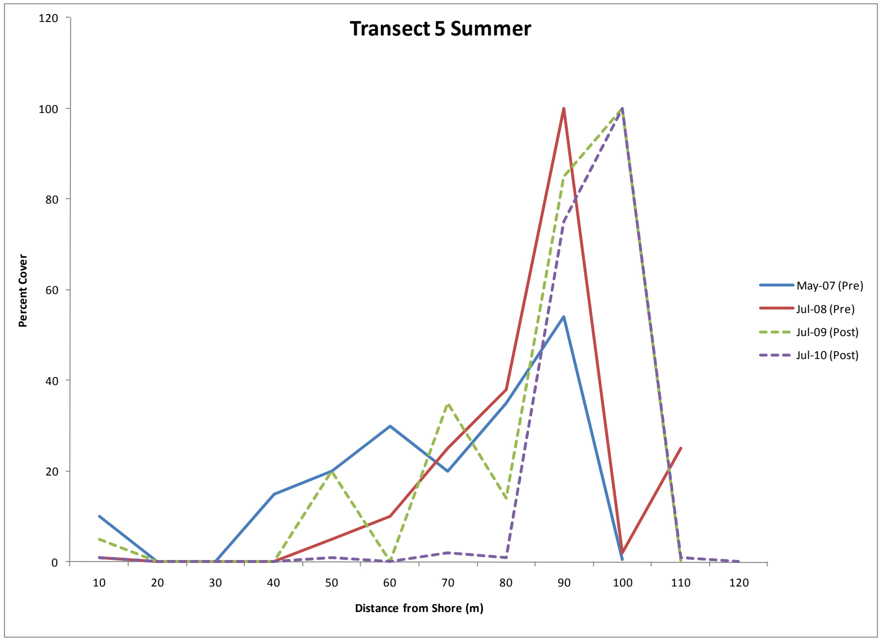
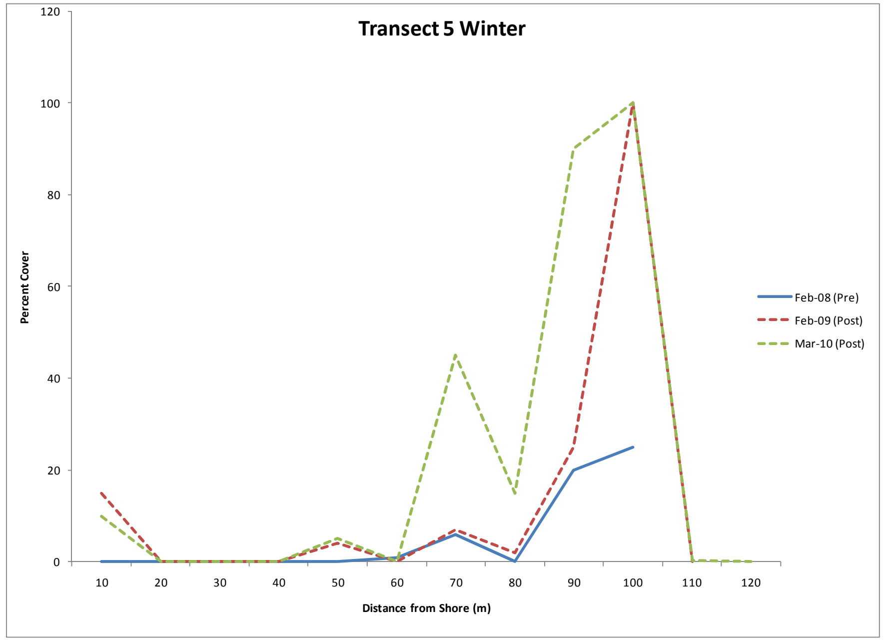
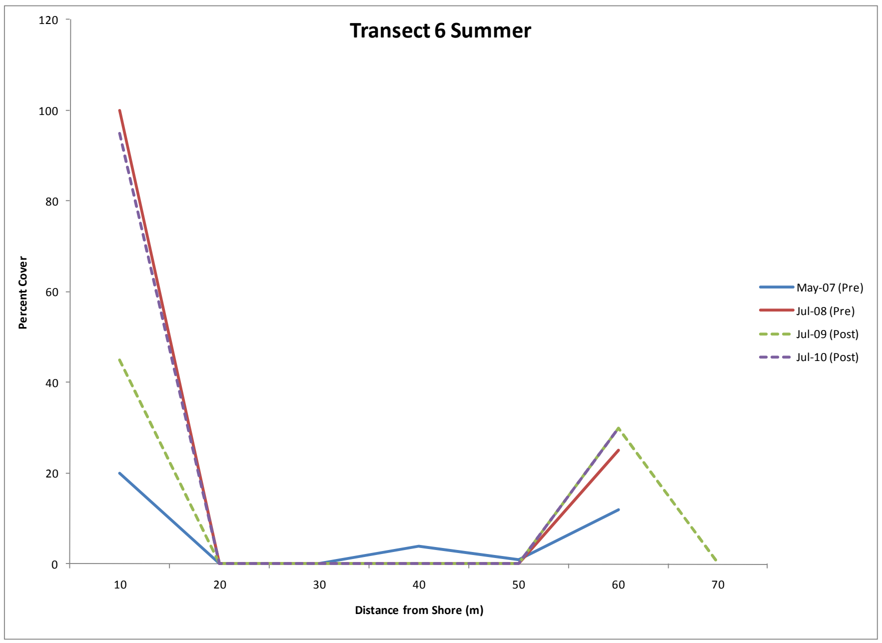


Figure 36 (continued). Time series plots (2007-2010) depicting visual percent cover of total seagrass by distance from shore for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).







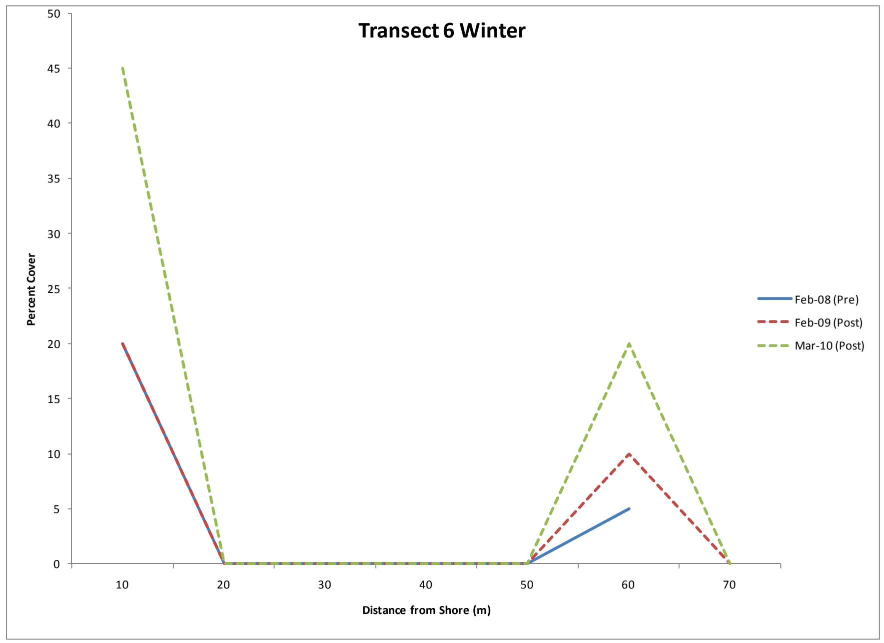


Figure 36 (continued). Time series plots (2007-2010) depicting visual percent cover of total seagrass by distance from shore for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).

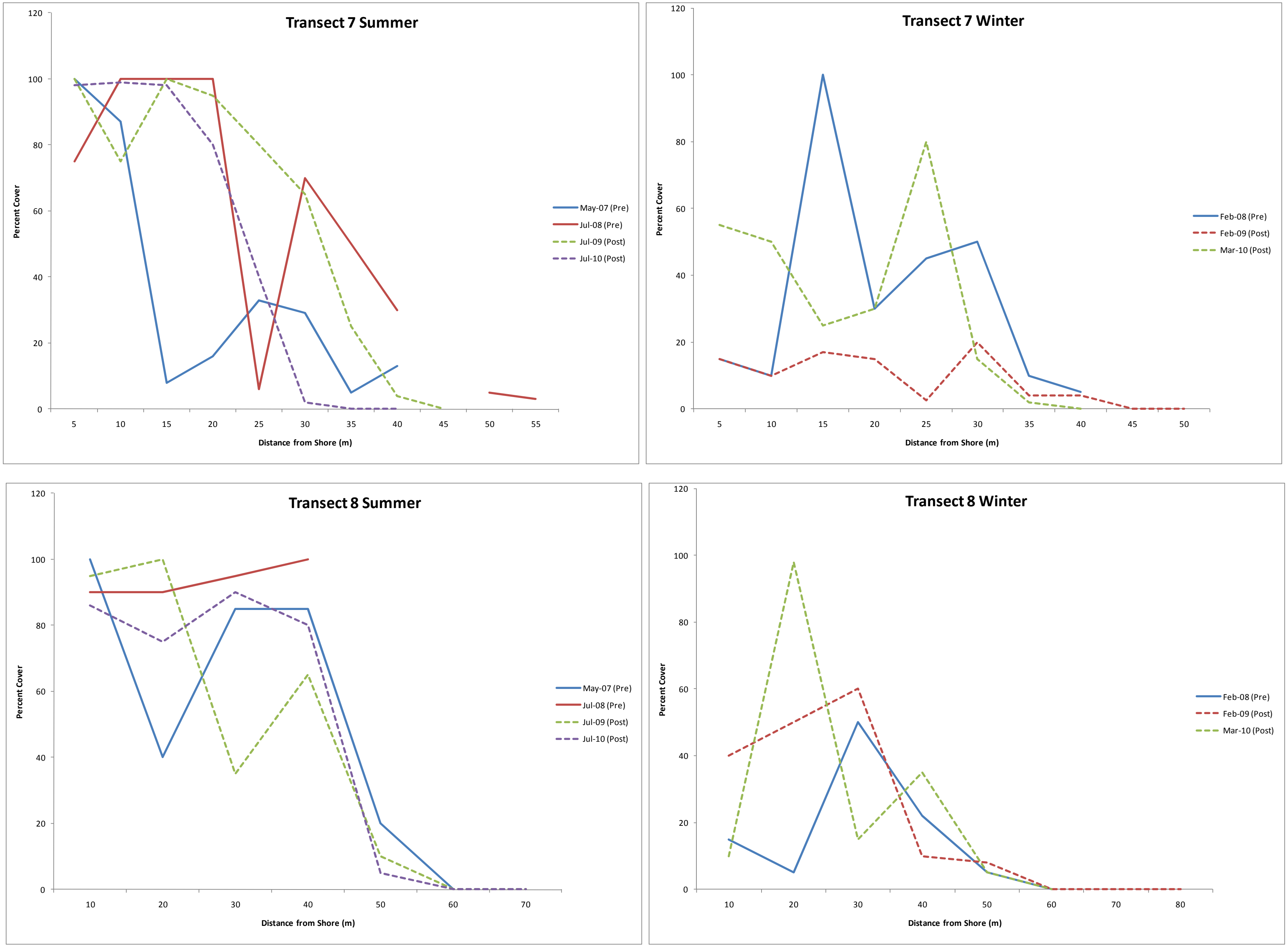


Figure 36 (continued). Time series plots (2007-2010) depicting visual percent cover of total seagrass by distance from shore for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).

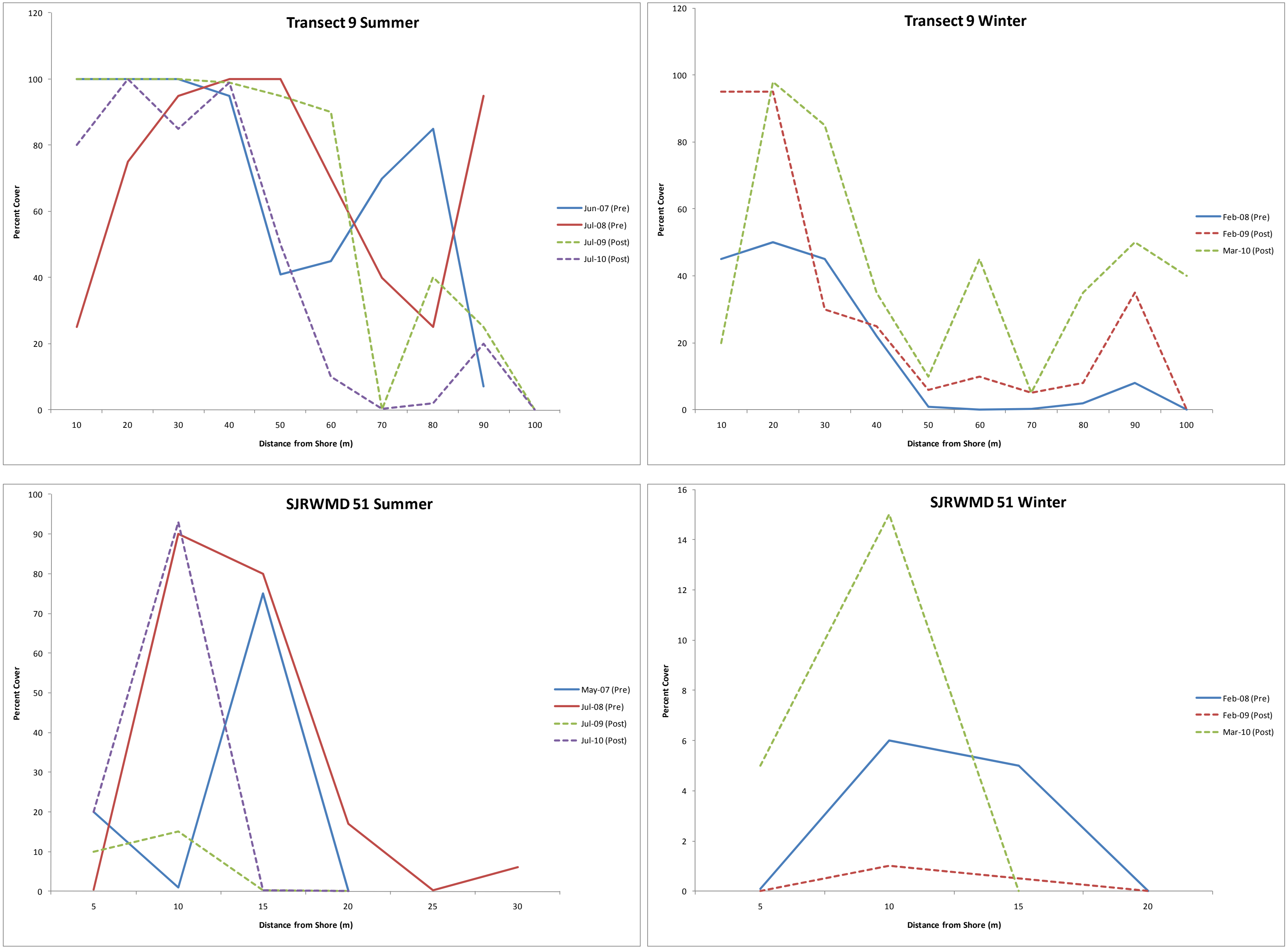


Figure 36 (continued). Time series plots (2007-2010) depicting visual percent cover of total seagrass by distance from shore for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).

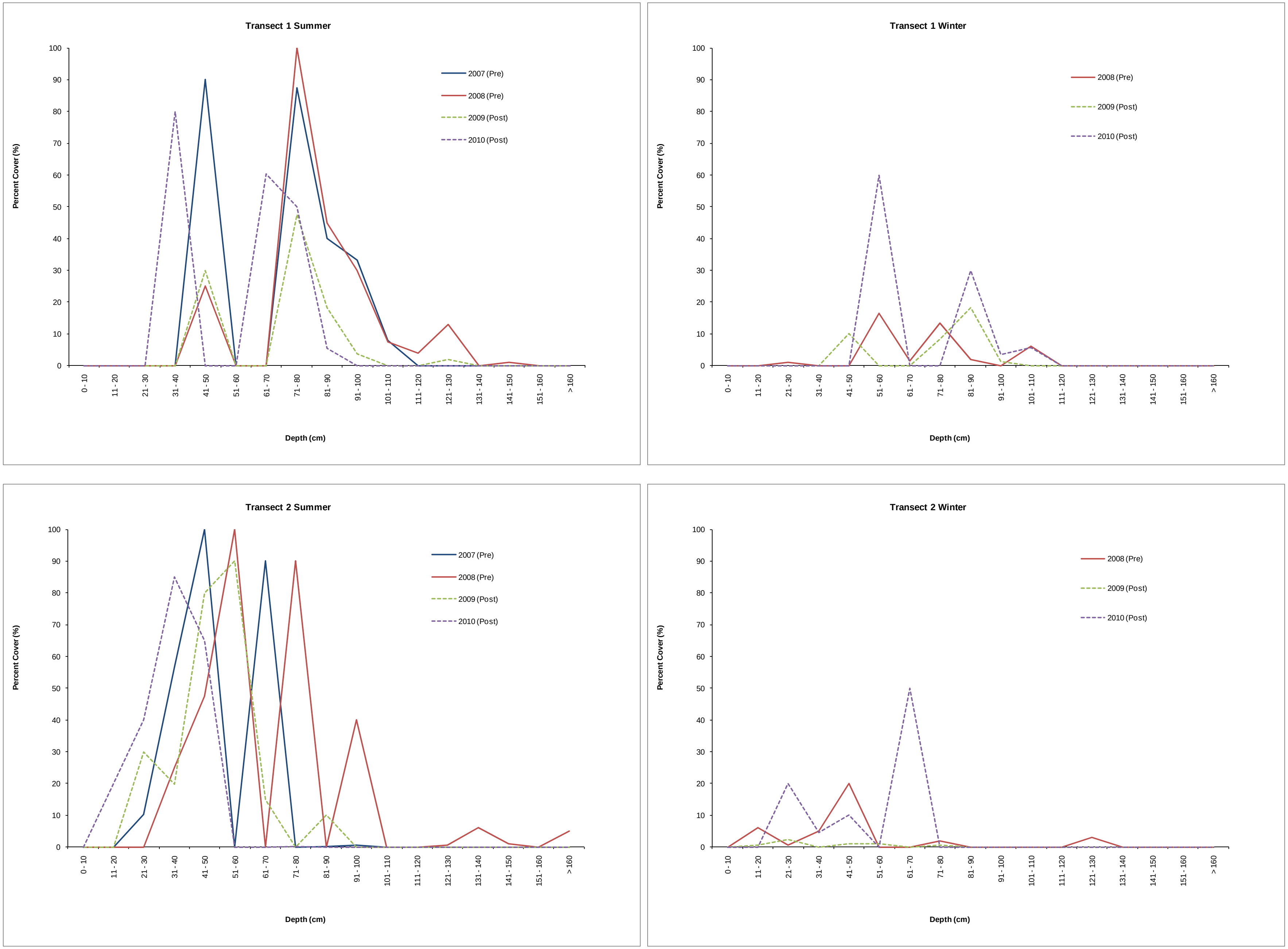


Figure 37. Time series plots (2007-2010) depicting visual percent cover of total seagrass by depth for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).

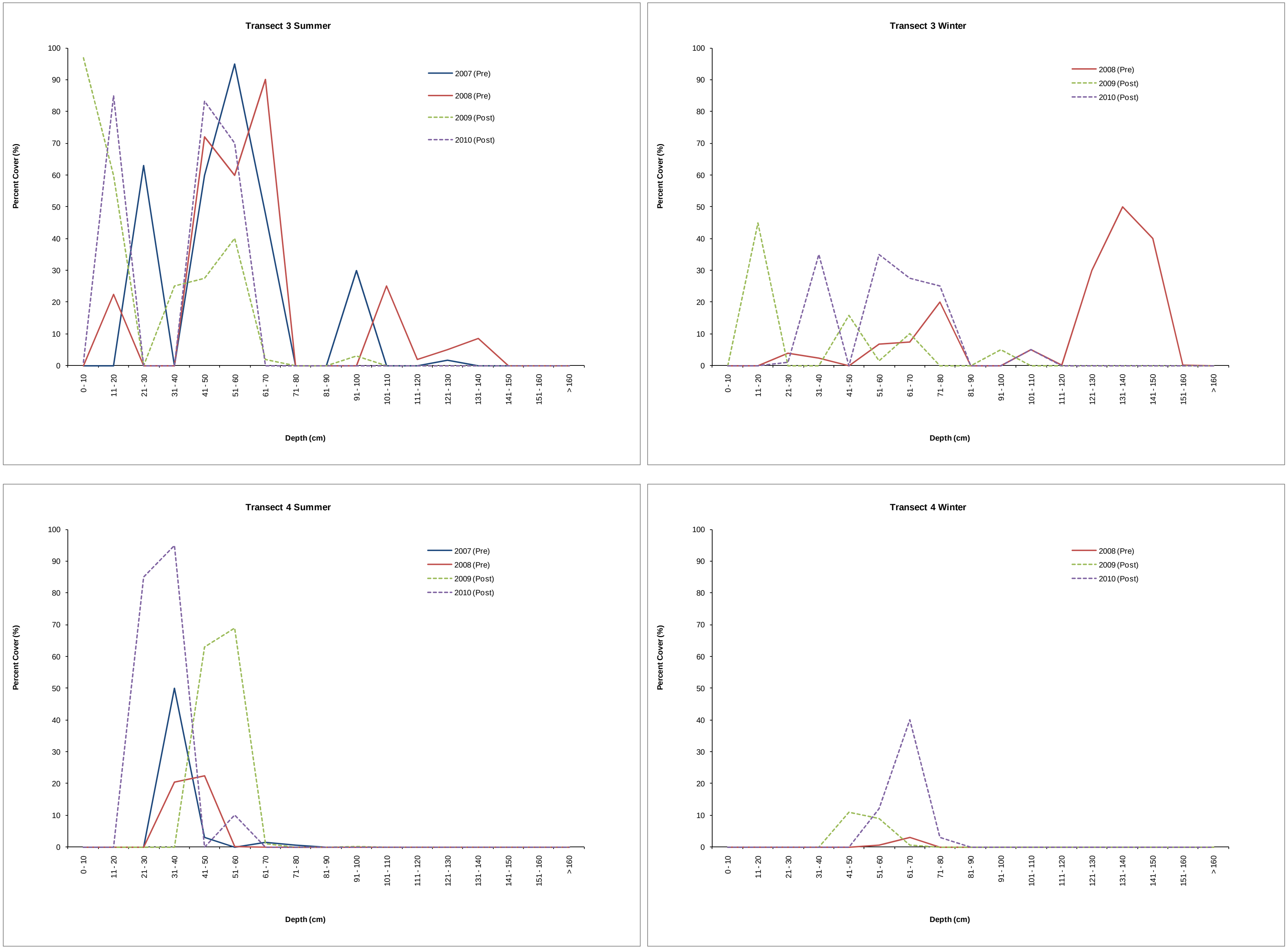
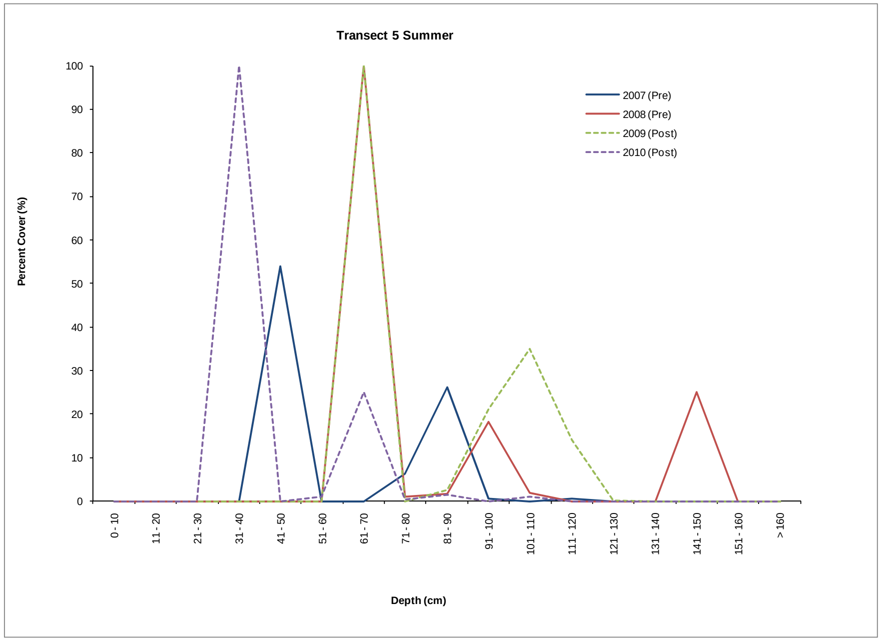
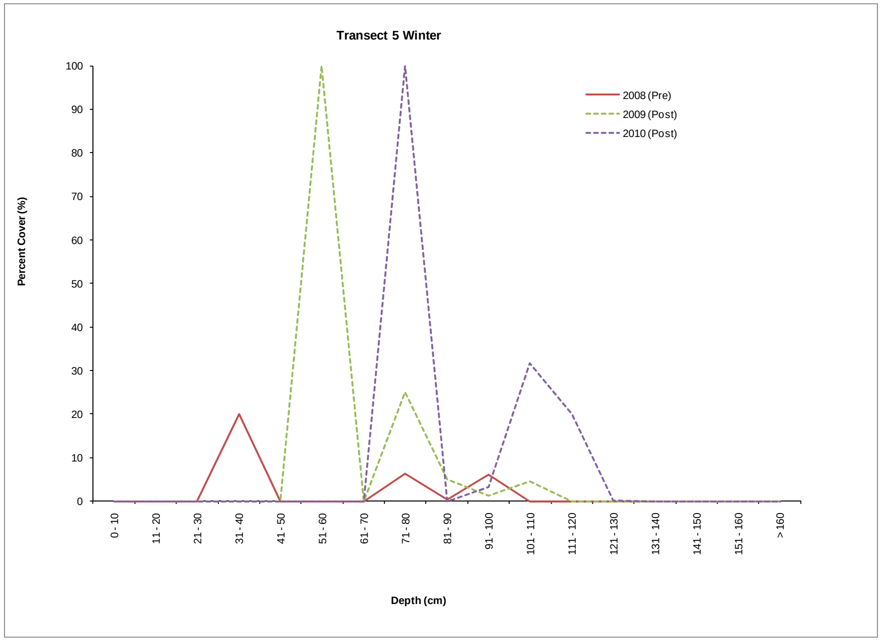
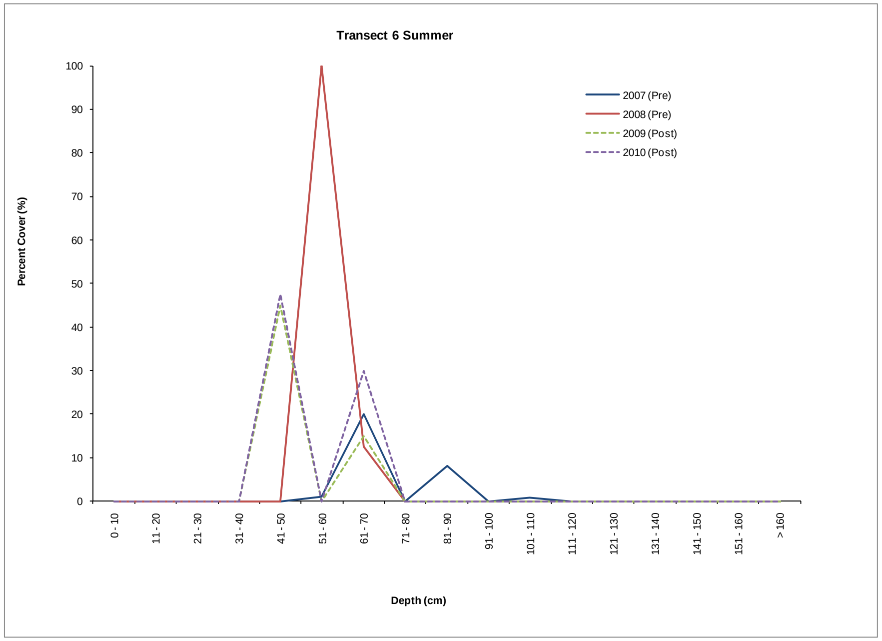


Figure 37 (continued). Time series plots (2007-2010) depicting visual percent cover of total seagrass by depth for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).







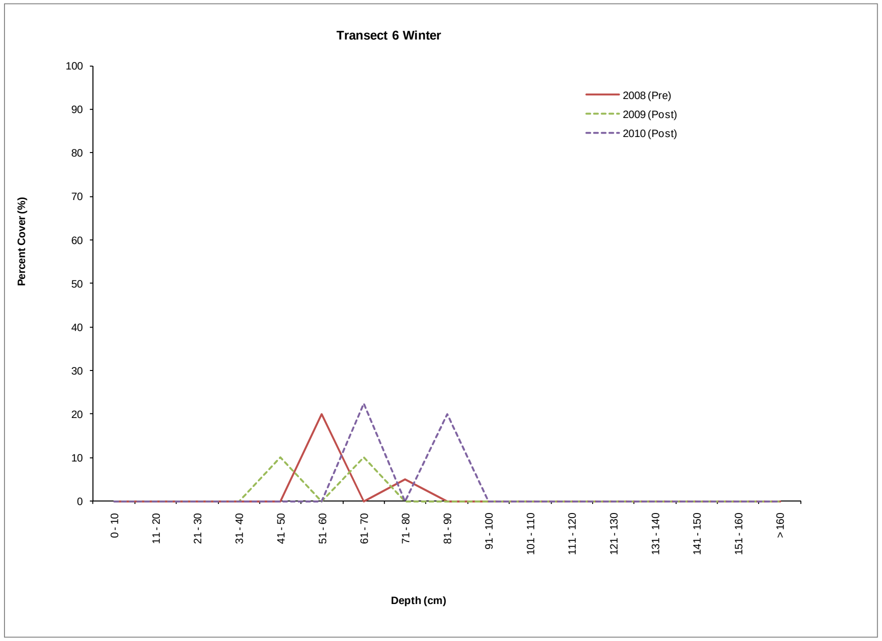
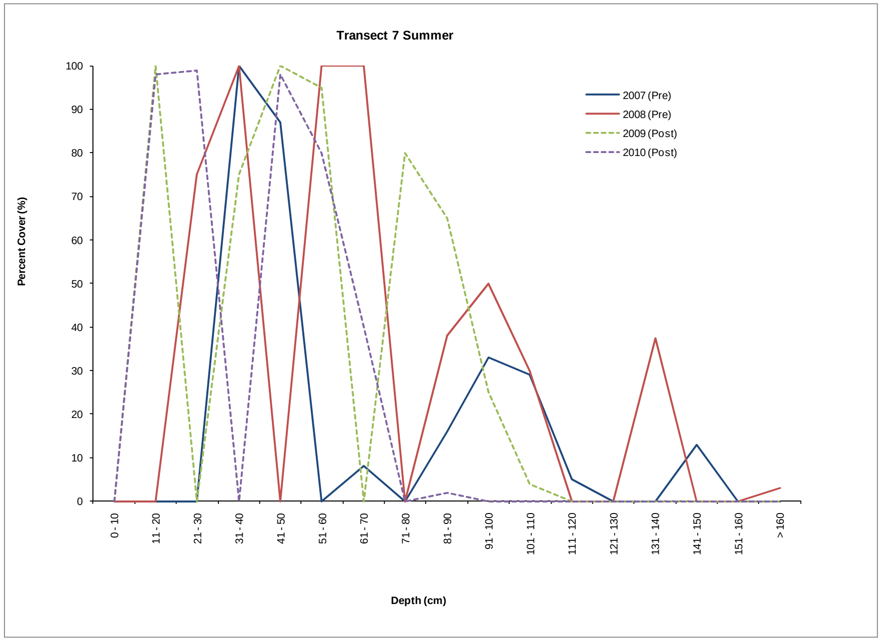
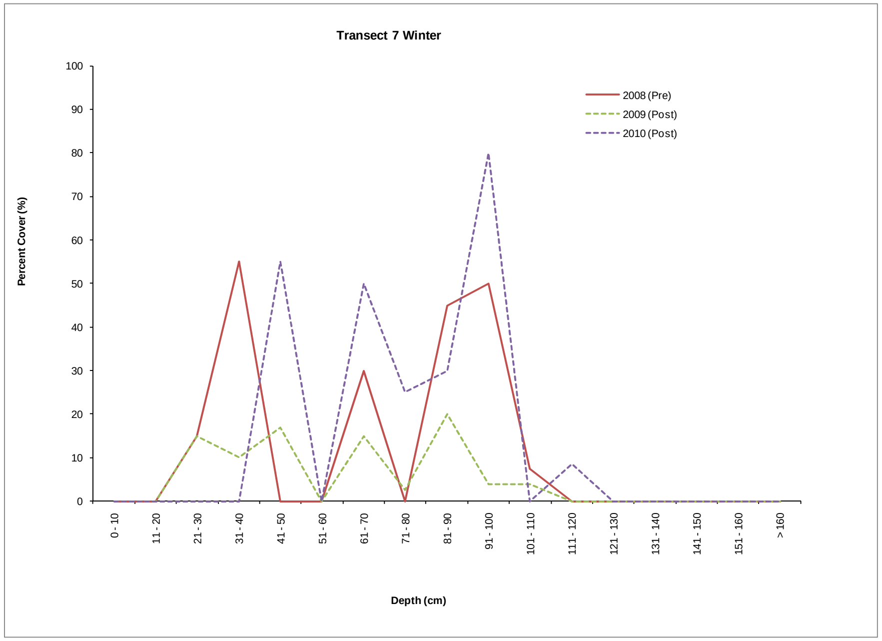
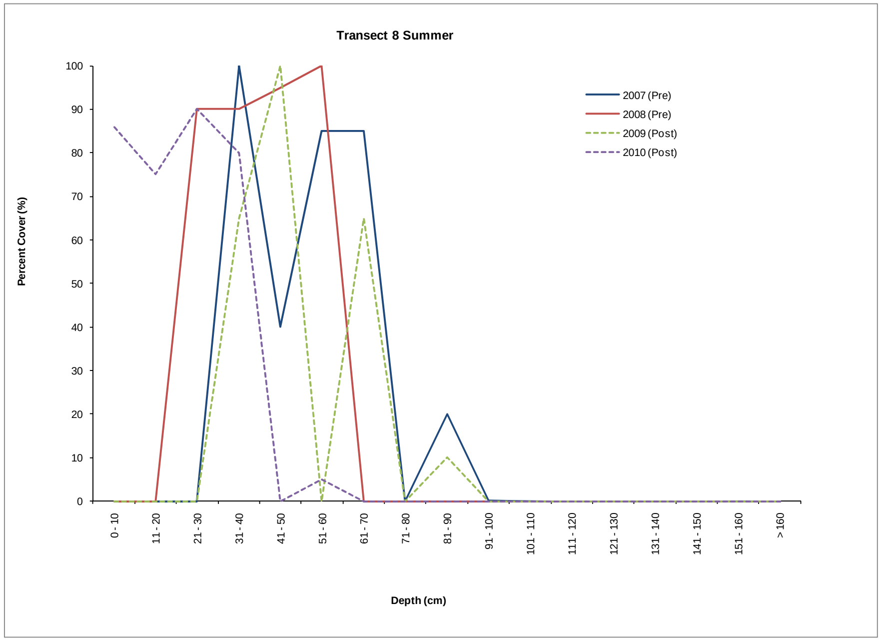


Figure 37 (continued). Time series plots (2007-2010) depicting visual percent cover of total seagrass by depth for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).







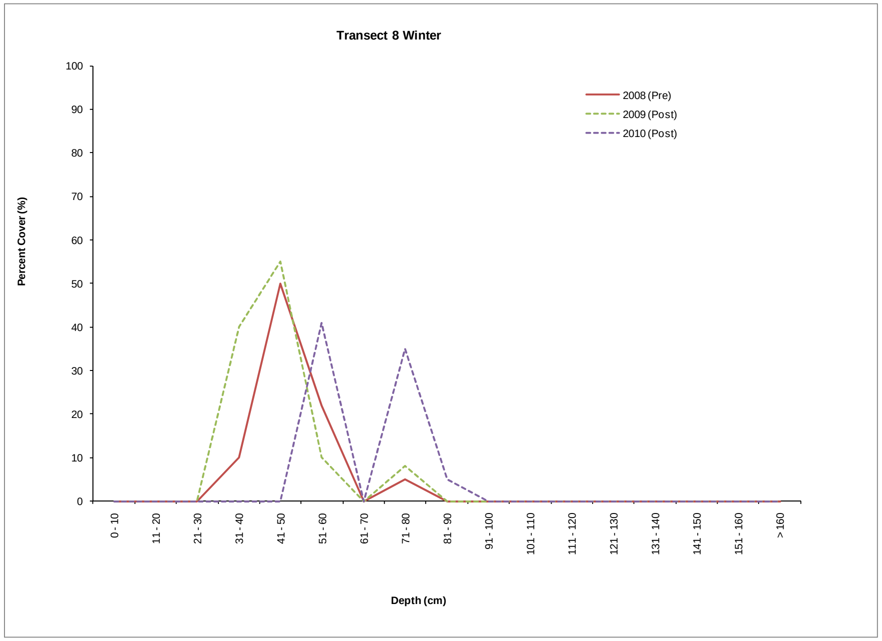


Figure 37 (continued). Time series plots (2007-2010) depicting visual percent cover of total seagrass by depth for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).

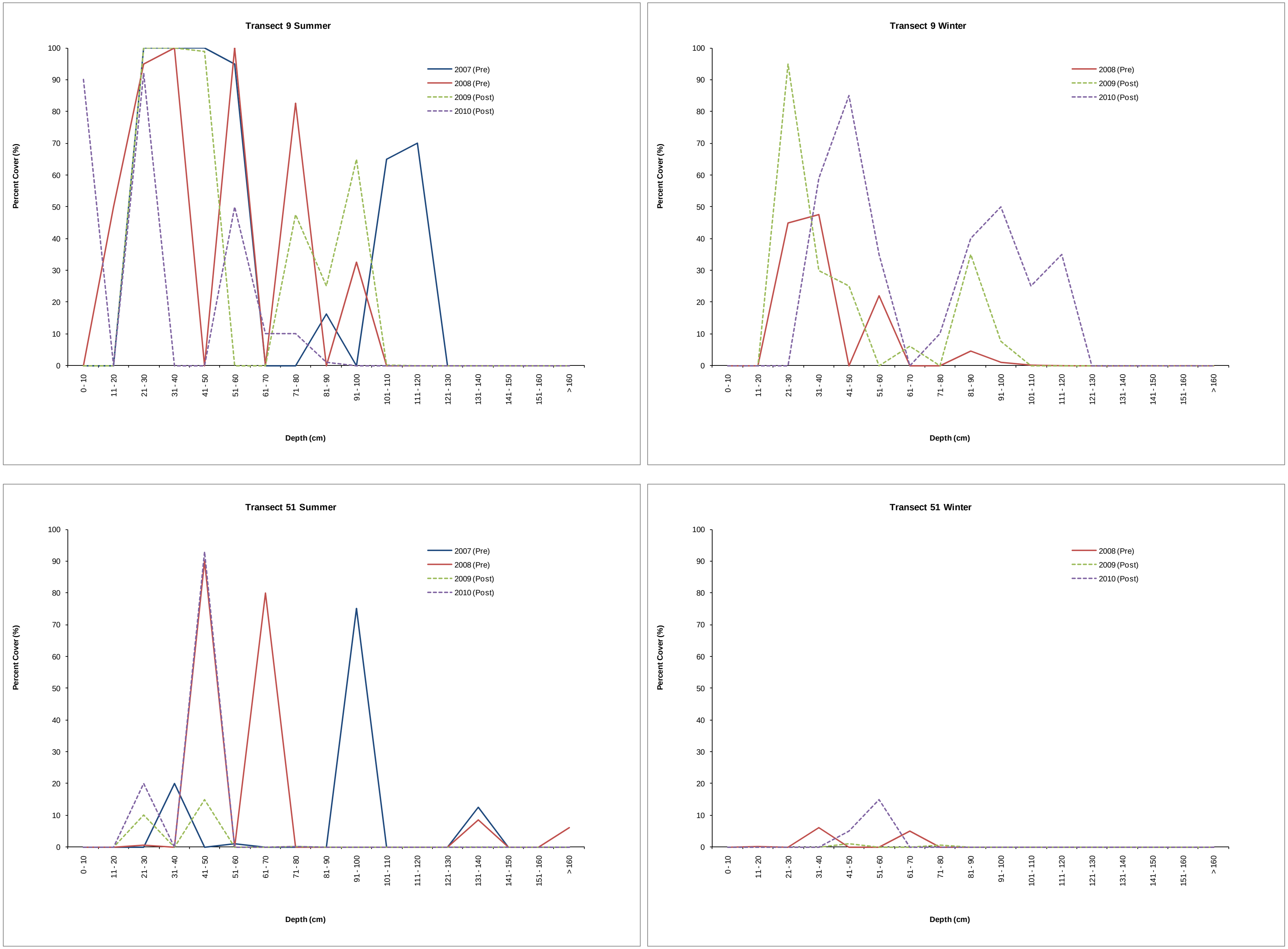


Figure 37 (continued). Time series plots (2007-2010) depicting visual percent cover of total seagrass by depth for all transects in the vicinity of the Indian River Main Relief Canal, Vero Beach, FL (Summer, N=4; Winter, N=3).

4.0 Literature Cited

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