

**SEGMENT III BROWARD COUNTY SHORE PROTECTION PROJECT
FDEP PERMIT 0163435-001-JC
18-MONTH POST-CONSTRUCTION NEARSHORE ENVIRONMENTAL
MONITORING SUMMARY REPORT**

Prepared for:

Broward County

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Main Report

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January 2008

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Executive Summary

INTRODUCTION

Segment III of the Broward County Shore Protection Project (SPP) is located between Port Everglades and the Broward/Miami-Dade County line. The project fill area in Segment III is approximately 10.97 kilometers (6.8 miles) in length. Beach fill extended from Florida Department of Environmental Protection (FDEP) monuments R-85.7 (Port Everglades south jetty) to R-92 within John U. Lloyd State Park, and from R-99 (Dania Beach Pier) to R-128 (Miami-Dade County line). The constructed sand fill volume for Segment III was approximately 1.92 million cubic yards of sand. The project was constructed in accordance with the following permits:

- FDEP Bureau of Beaches and Coastal Systems
 - Joint Coastal Permit No. 0163435-001-JC, Broward County
 - Broward County Beach Nourishment Project Segment III
 - Date of Issuance: May 12, 2003
 - Date of Expiration: May 12, 2008
 - Permit Modification No. 0163435-009-JC
 - Modification to Include Borrow Area I
 - Date of Issuance: June 22, 2005
 - Permit Modification No. 0163435-010-EM
 - Modification to Deepen a Portion of Borrow Area III
 - Date of Issuance: June 17, 2005
 - Permit Modification No. 0163435-011-EM
 - Added Pipeline Corridors and Operational Boxes to Permit and allowed a Modification to Pipeline Corridor No. 5
 - Date of Issuance: November 29, 2005
 - Permit Modification No. 0163435-013-EM
 - Modification of Borrow Area I and II Slope Cuts
 - Date of Issuance: January 13, 2006
 - Joint Coastal Permit No. 0226688-001-JC
 - Port Everglades Entrance Channel Shoal Removal
 - Date of Issuance: November 4, 2004
 - Date of Expiration: November 4, 2009
- US Army Corps of Engineers – Jacksonville District
 - Department of the Army (DOA) Permit No. SAJ-1999-5545 (IP-SLN) – (Date of Issuance: July 16, 2004)
 - Modification #1 of (DOA) Permit No. SAJ-1999-5545(IP-SLN) to allow removal of a Port Everglades Entrance Channel sand shoal and place the

material along the John U. Lloyd Beach State Park project shoreline. (Date of Issuance: August 17, 2004)

- Modification #2 of (DOA) Permit No. SAJ-1999-5545(IP-SLN) to allow placement of sand removed from the Port Everglades sand shoal along the entire Segment III project shoreline. (Date of Issuance: October 20, 2004).
- Modification #3 of (DOA) Permit No. SAJ-1999-5545(IP-SLN) to modify the vertical excavation limits of a portion of BA-III. (Date of Issuance: June 6, 2005).
- Modification #4 of (DOA) Permit No. SAJ-1999-5545 (IP-SLN) to modify the vertical excavation limits of portions of BA-I and BA-II (Date of Issuance: January 13, 2006).

Based on a survey conducted in 1991, placement of sand during nourishment activities and subsequent equilibration of the beach fill was predicted to result in the burial of approximately $3.07 \times 10^{-2} \text{ km}^2$ (7.6 acres) of nearshore hardbottom in Segment III, including direct burial of $3.64 \times 10^{-3} \text{ km}^2$ (0.9 acres) in John U. Lloyd State Park and $4.45 \times 10^{-3} \text{ km}^2$ (1.1 acres) of wormrock habitat in Hollywood. Due to the projected burial of natural hardbottom areas, the FDEP required the placement of $3.60 \times 10^{-2} \text{ km}^2$ (8.9 acres) of mitigative artificial reef. The potential for damage to natural hardbottoms due to beach construction efforts and subsequent equilibration resulted in permit conditions mandating an assessment of the potential impacts to the nearshore habitat. Construction of the project began in May 2005 and concluded in February 2006.

SUMMARY OF RESULTS

Data analysis consisted of parametric and non-parametric analyses. Non-parametric analysis was performed using PRIMER® (v6) statistical package (Clarke and Warwick, 2001; Clarke and Gorley, 2006). Statistical significance is determined at $\alpha = 0.05$ (95% confidence interval). All reference to “significance” has been determined through statistical calculation. This executive summary is meant to aid the reader in understanding the project goals and results; however, it is not recommended to rely solely on this summary for a complete understanding of project impacts.

The 2005 hurricane season coincided with mid-construction; both of which likely contributed to the community changes ascertained through statistical analysis of the biological dataset. The monitoring of control transects outside the beach construction area allowed for the differentiation of project effects versus natural storm activity effects in the project area (experimental transects). It was determined that the combined effects of the 2005 hurricane season and beach construction contributed to changes in the benthic biological community between pre- and post-construction.

Prior to project construction, it was anticipated that fill equilibration would consist of a gradual migration of the nearshore edge and that full equilibration would be reached approximately three years following completion of project construction. It is now believed, however, that the storm conditions of 2005 (project construction period) may have drastically altered cross-shore and alongshore processes compared to those of “normal” weather conditions and typical beach fill equilibration processes. Further, these storm-induced seaward migrations of the nearshore edge

are now seen to be recovering, resulting in a continuing trend of shoreward migration of the nearshore edge. Thus barring future significant storm impacts, it is likely that by three years post-construction, net hardbottom coverage will be in order-of-magnitude range of pre-project predictions.

The detailed analysis of sediment dynamics on the 92-m transects has revealed a pulse of sand movement from west to east (landward to seaward) that gradually tapers to offshore areas. Temporary, high-level sediment accumulation occurred on the nearshore 30 meters of hardbottom and more persistent, low-level sand accumulation occurred on the offshore 62 meters of hardbottom. By 18-month post-construction there was no significant difference between controls and experimental sites in the nearshore 30 meters of hardbottom, whereas the sand layer in the offshore 62 meters of transects remained significantly higher at experimental sites.

Water quality monitoring for turbidity during post-construction indicated no project-related effects discernable from natural conditions, and that turbidity levels in all control and compliance sites remained relatively low throughout post-construction monitoring. Mid-construction weekly turbidity monitoring reports were submitted to FDEP and can be found on the Coastal Planning & Engineering, Inc. (CPE) ftp website.

Biological monitoring of the benthic community using Benthic Ecological Assessment of Marginal Reefs (BEAMR) methodology revealed sand cover to be the dominant influence in community change over time and space. A distinct differentiation in community composition on the experimental transects coincided with the commencement of beach construction; however by 18-month post-construction, the biotic benthic community at the functional group level had recovered to pre-construction conditions on half of the experimental transects.

Nearshore hardbottom areas displayed a significant loss in macroalgae resources preferred by *Chelonia mydas* (green sea turtle) following the mid-construction monitoring event. The macroalgae community in the control sites recovered to pre-construction conditions by 12-month post-construction, but the experimental sites had not recovered to pre-construction conditions by 18-month post-construction. This implies that the beach nourishment project may result in prolonged impacts to this particular community. Coinciding with the loss in macroalgae, a decline in the juvenile green sea turtle observations was reported by Makowski *et al.* (2007) between pre- and post-construction in Segment III.

Through time, community patterns in coral species abundance and cover on the nearshore hardbottom in the area indicated a declining shift following the commencement of beach construction; however, the scale of these shifts transcends treatment type, implicating the unusually strong hurricane seasons of 2004-2005 in these patterns. General trends in relative coral density were stationary through time and statistically indistinguishable between control and experimental treatment areas. Temporal trends in probability of occurrence indicate that *Siderastrea* spp. may have been most impacted coral species, most likely as a result of this species low relief and tendency to dominate the ephemeral nearshore edge of hardbottom in Broward County.

Coral stress levels were investigated in short and long-term time scales to determine if beach construction affected stress levels of three scleractinian species (*Montastrea cavernosa*, *Solenastrea bournoni*, and *Siderastrea siderea*). Tracking coral health over the monitoring period revealed significantly higher coral stress levels at the experimental sites compared to the control sites. These results, in conjunction with the sediment depth analysis, suggest that the scleractinian community health was adversely impacted by sediment migration off the beaches onto the nearshore hardbottom environment. However, by 15-month post-construction, the stress levels at the control and experimental transects were indistinguishable suggesting project related stress was temporary.

The purpose of coral fate-tracking stations was to quantify changes in stony coral colonies on first-reef habitat disassociated with the nearshore hardbottom edge. The probability of coral mortality differed based on coral morphological type (either branching or massive). Mortality in branching form corals was 16-times that of massive form corals; the greatest single loss of branching form corals was observed immediately post-construction, which was the first monitoring effort after the active 2005 hurricane season. One coral species of particular interest in the coral fate-tracking was *Acropora cervicornis* due to its designation as an endangered species. There were five (5) *Acropora cervicornis* colonies monitored within the stations and only three (3) survived as of 18-month post-construction. Out of these three, only one colony showed any growth. The remaining two *A. cervicornis* colonies decreased in size over the two year time period.

CONCLUSION

High resolution monitoring of Segment III in the Broward County SPP revealed a benthic community that has experienced habitat loss as a result of beach nourishment activities; however the subsequent re-emergence of habitable substrate indicates that the loss may be temporary. Further monitoring will reveal if persistent loss exists as the final impact of fill equilibrium is expected to occur 36 months post-construction.

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Supplement

18-Month Post-Construction Nearshore Environmental Monitoring Report

SEGMENT III BROWARD COUNTY SHORE PROTECTION PROJECT

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- III Details of monitoring events
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Broward County: The Second Post-Construction Assessment
- XI BEAMR Coral Data by Transect
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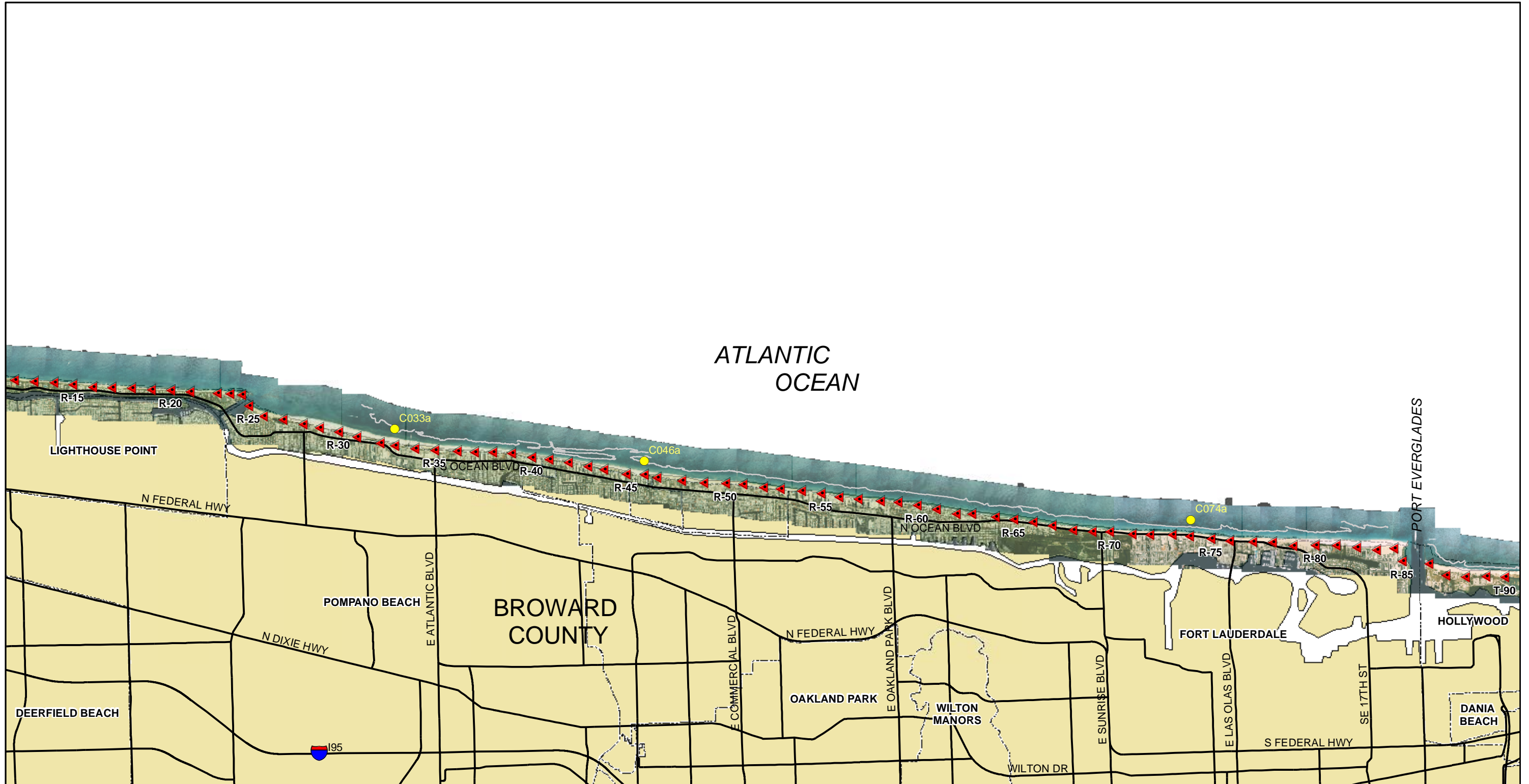
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1.0 INTRODUCTION

Segment III of the Broward County Shore Protection Project (Florida Department of Environmental Protection [FDEP] Permits 0163435-001-JC and 0226688-001-JC, with various modifications; Department of the Army Permit SAJ-1999-5545 (IP-SLN), with various modifications) is located between Port Everglades and the Broward/Miami-Dade County line. The project fill area in Segment III is approximately 10.97 kilometers (6.8 miles) in length. The project provided beach renourishment for the majority of the Segment III shoreline including John U. Lloyd State Park, City of Dania Beach, City of Hollywood, and City of Hallandale Beach shorelines. Beach fill extended from Florida Department of Environmental Protection (FDEP) monuments R-85.7 (Port Everglades) to R-92 within John U. Lloyd State Park, and from R-98.3 (Dania Beach Pier) to R-128 (Dade County line) (Figure 1). The constructed sand fill volume placed in Segment III was approximately 1.92 million cubic yards.

The primary design objectives of the Segment III, Broward County Shore Protection Project (SPP) were to: restore eroded sections of the authorized Federal project design beach berm, provide at least 6 years of advance beach nourishment, and improve fill performance through beach fill taper modifications at the northern end of the City of Hollywood and the southern end of City of Hallandale Beach. These actions occurred in concert with the construction of three shore-stabilizing structures at the northern end of the John U. Lloyd Beach State Park project reach. The 2001 beach fill design called for the placement of 440,000 cubic yards of sand along the John U. Lloyd Beach State Park (JUL) shoreline and 1,100,000 cubic yards of sand along the Hollywood/Hallandale/Dania (HHD) shoreline. The placement of sand during nourishment activities and subsequent equilibration of the beach fill was predicted to result in the burial of approximately $3.07 \times 10^{-2} \text{ km}^2$ (7.6 acres) of nearshore hardbottom and associated hardbottom resources, including direct burial of $3.64 \times 10^{-3} \text{ km}^2$ (0.9 acres) of hardbottom in John U. Lloyd State Park and $4.45 \times 10^{-3} \text{ km}^2$ (1.1 acres) of wormrock habitat in Hollywood. The Segment III project was constructed between 14 May 2005 and 8 February 2006. The project was deemed Substantially Complete on 2 March 2006.

Due to the projected burial of natural hardbottom areas, the FDEP required the placement of $3.60 \times 10^{-2} \text{ km}^2$ (8.9 acres) of mitigative artificial reef. The artificial reef was constructed as one layer of limestone boulders (2.0 – 2.8 m in maximum diameter) placed in the nearshore zone in approximately 4 to 6 m mean water depth. Construction of the mitigative artificial reef started in August 2003 and was completed in September 2003, twenty months before construction of the beach nourishment project. In addition to boulder placement, measures were taken to enhance the habitat value of the mitigation and to minimize the impact of the beach nourishment. The additional mitigation was provided to decrease the time until the mitigation substrate reached habitat equivalency to the adjacent natural substrate. The additional mitigation included transplantation of stony corals from construction impact areas to the boulders placed at Mitigation Area #7, between FDEP monuments R-101 and R-102 (Figure 2).

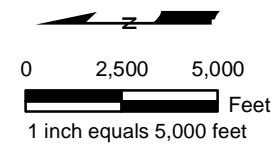


NOTES:

1. DATE OF AERIAL PHOTOGRAPHY: 04/07/2007,
FLOWN BY SOUTHERN RESOURCE MAPPING OF
MIAMI, INC. (SRM MIAMI).

LEGEND

- CONTROL TRANSECT LOCATIONS
- 2001 HARDBOTTOM EDGE
- ▲ FDEP MONUMENTS



**BROWARD COUNTY
SEGMENT II
CONTROL NEARSHORE TRANSECTS**



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Date: 10/31/07 By: DNR COMM NO: 5353.24 **FIGURE 1a**

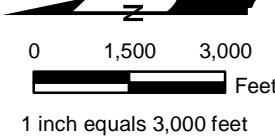


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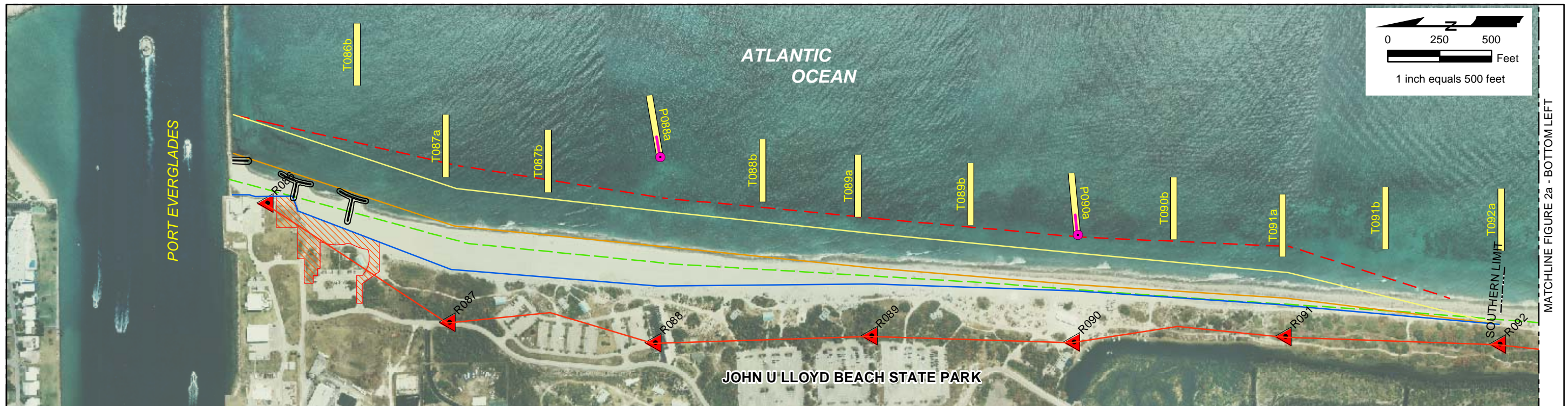
1. DATE OF AERIAL PHOTOGRAPHY: 04/07/2007,
FLOWN BY SOUTHERN RESOURCE MAPPING OF
MIAMI, INC. (SRM MIAMI).

LEGEND

- CORAL FATE TRACKING STATIONS
- CONTROL TRANSECT LOCATIONS
- 2001 HARBOTTOM EDGE
- FDEP MONUMENTS



BROWARD COUNTY SEGMENT III CONTROL NEARSHORE TRANSECTS		
COASTAL PLANNING & ENGINEERING, INC		
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Date: 10/31/07	By: DNR	COMM NO: 5353.24
		FIGURE 1b



NOTES:

1. DATE OF AERIAL PHOTOGRAPHY: 04/07/2007.
2. ARTIFICIAL REEF COORDINATES PROVIDED BY COASTAL SYSTEMS INTERNATIONAL, INC., 2003.
3. TRANSECT LABELS DISTINGUISH THREE NESTED SAMPLING SCHEDULES: DURING BEACH CONSTRUCTION (C, N, O, P, T), PRE- AND POST- BEACH CONSTRUCTION (C, O, P), AND MITIGATION REEF ASSESSMENT (A, C, N, O, P).
4. FOR LOCATIONS OF ALL PROJECT CORAL FATE TRACKING STATIONS (8 TOTAL) SEE SHEET 1b.

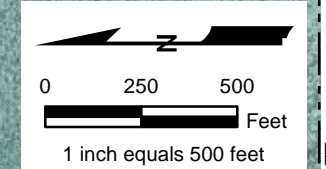
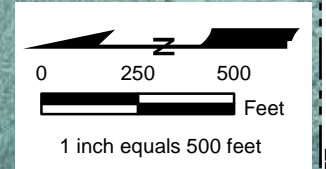
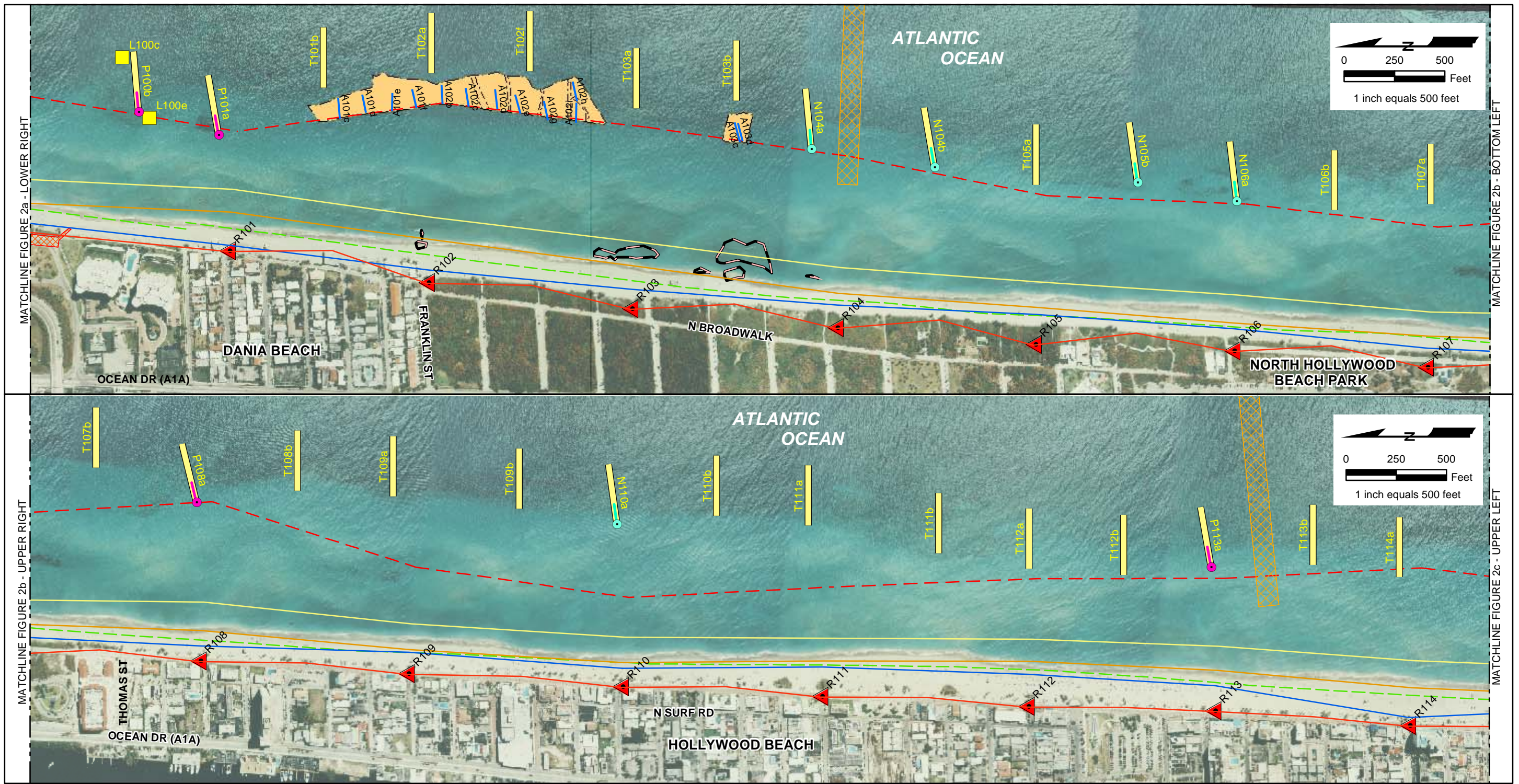
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- | | |
|------------------------|--|
| 92 METER TRANSECT | 30 METER CONTROL TRANSECT (C) |
| SEAWARD LIMIT OF FILL | 30 METER NATURAL MITIGATION TRANSECT (N) |
| TOP OF BERM | 30 METER NATURAL PERMANENT TRANSECT (P) |
| LANDWARD LIMIT OF FILL | EQUILIBRIUM TOE OF FILL |
| EROSION CONTROL LINE | STAGING AREA AND CONSTRUCTION ACCESS |
| BASELINE | PROJECT LIMIT - (SEGMENT 3) |
| | FDEP MONUMENTS |

**BROWARD COUNTY
SEGMENT III
PERMANENT NEARSHORE TRANSECTS**

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Date: 10/31/07 | By: DNR | COMM NO: 5353.24 | **FIGURE 2a**



NOTES:

1. DATE OF AERIAL PHOTOGRAPHY: 04/07/2007.
2. ARTIFICIAL REEF COORDINATES PROVIDED BY COASTAL SYSTEMS INTERNATIONAL, INC., 2003.
3. TRANSECT LABELS DISTINGUISH THREE NESTED SAMPLING SCHEDULES: DURING BEACH CONSTRUCTION (C, N, O, P, T), PRE- AND POST- BEACH CONSTRUCTION (C, O, P), AND MITIGATION REEF ASSESSMENT (A, C, N, O, P).
4. FOR LOCATIONS OF ALL PROJECT CORAL FATE TRACKING STATIONS (8 TOTAL) SEE SHEET 1b.

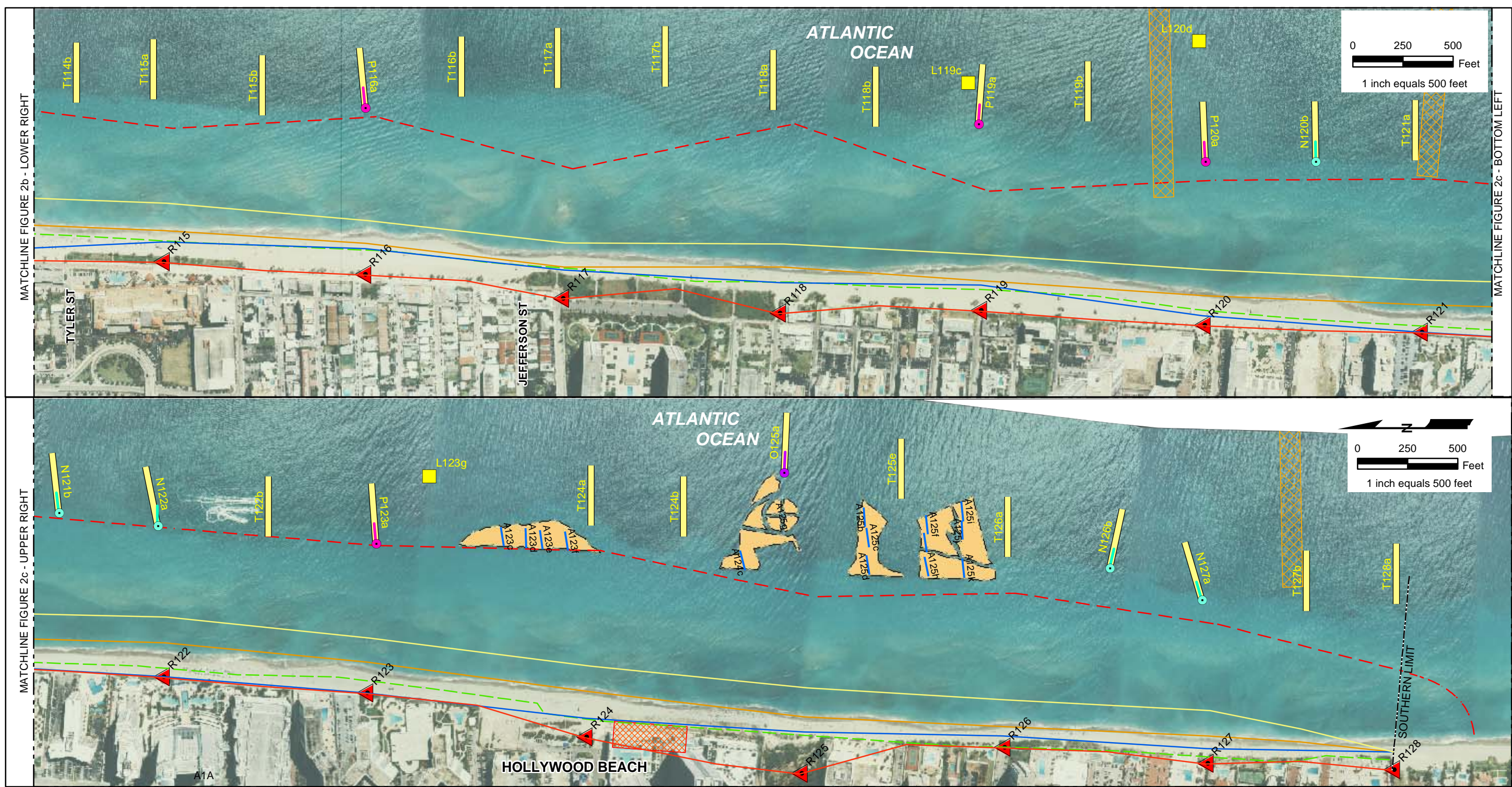
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|-----------------------------|--|
| 92 METER TRANSECT | 30 METER CONTROL TRANSECT (C) |
| SEAWARD LIMIT OF FILL | 30 METER NATURAL MITIGATION TRANSECT (N) |
| TOP OF BERM | 30 METER NATURAL PERMANENT TRANSECT (P) |
| LANDWARD LIMIT OF FILL | 30 METER ARTIFICIAL REEF TRANSECTS (A) |
| EROSION CONTROL LINE | PIPELINE CORRIDOR |
| BASELINE | ARTIFICIAL REEF AS-BUILT 7, 8 & 9 |
| EQUILIBRIUM TOE OF FILL | 2001 WORM ROCK LOCATION |
| CORAL FATE TRACKING STATION | STAGING AREA AND CONSTRUCTION ACCESS |
| | FDEP MONUMENTS |

**BROWARD COUNTY
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Date: 10/31/07 By: DNR COMM NO: 5353.24 **FIGURE 2b**



NOTES:

1. DATE OF AERIAL PHOTOGRAPHY: 04/07/2007.
2. ARTIFICIAL REEF COORDINATES PROVIDED BY COASTAL SYSTEMS INTERNATIONAL, INC., 2003.
3. TRANSECT LABELS DISTINGUISH THREE NESTED SAMPLING SCHEDULES: DURING BEACH CONSTRUCTION (C, N, O, P, T), PRE- AND POST- BEACH CONSTRUCTION (C, O, P), AND MITIGATION REEF ASSESSMENT (A, C, N, O, P).
4. FOR LOCATIONS OF ALL PROJECT CORAL FATE TRACKING STATIONS (8 TOTAL) SEE SHEET 1b.

LEGEND:

- 92 METER TRANSECT
- SEAWARD LIMIT OF FILL
- TOP OF BERM
- LANDWARD LIMIT OF FILL
- EROSION CONTROL LINE
- BASELINE
- EQUILIBRIUM TOE OF FILL
- CORAL FATE TRACKING STATION
- PIPELINE CORRIDOR
- 30 METER NATURAL MITIGATION TRANSECT (N)
- 30 METER NATURAL OTHER TRANSECT (O)
- 30 METER NATURAL PERMANENT TRANSECT (P)
- 30 METER ARTIFICIAL REEF TRANSECTS (A)
- ARTIFICIAL REEF AS-BUILT 10 & 11
- STAGING AREA AND CONSTRUCTION ACCESS
- FDEP MONUMENTS

**BROWARD COUNTY
SEGMENT III
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The nearshore monitoring transects referenced in this report were located and named to detect potential secondary impacts after beach construction of the Broward County SPP. The 17 transects were assigned a prefix which designate their function as a control (C) or an experimental (P and O) transect and include:

- C for control transects (5)
- P for permanent experimental transects (11)
- O for other experimental transects (1)

The Segment III project was constructed between 14 May 2005 and 8 February 2006. The project was deemed Substantially Complete on 2 March 2006. This post-construction report is a synoptic presentation of findings concerning environmental impacts to nearshore hardbottom and biological resources up to and including the 18th month of post-construction monitoring. The full details of this report, including detailed experimental design, methodology, statistical analyses, and conclusions are provided in the Supplement, attached hereto with appendices.

1.1 Reporting

Data analysis consisted of parametric and non-parametric analyses. Statistical significance was determined at $\alpha = 0.05$ (95% confidence interval). Throughout this Summary Report and the Supplement, all reference to “significance” has been determined through statistical analysis. Non-parametric analysis was performed using PRIMER-E (v6) statistical package (Clarke and Warwick, 2001; Clarke and Gorley, 2006).

Due to the high number of monitoring events analyzed, the construction events were sometimes grouped for ease of presentation. When monitoring groups are used, they are consistent throughout analysis and are referenced as presented in Table 1, unless otherwise noted.

Table 1. Naming scheme for grouped monitoring periods and the events included in each period.

Grouped Monitoring Period	Events Included in Monitoring Period
Pre-construction	12-, 8-, and 2-month pre-construction
Mid-construction	Week 15 mid-construction
0-2 Post	0-, 1-, and 2-month post-construction
3-5 Post	3-, 4-, and 5-month post-construction
6-8 Post	6-, 7-, and 8-month post-construction
9-12 Post	9-, 10-, 11-, and 12-month post-construction
14-15 Post	14- and 15-month post-construction
16-18 Post	16-, 17-, and 18-month post-construction

2.0 BIOLOGICAL MONITORING PLAN

The potential for damage to natural hardbottom and biological resources initiated the development of a Biological Monitoring Plan. This plan was prepared in compliance with the permits associated with the Broward County SPP. A portion of the monitoring outlined in the plan was designed to ascertain the impacts of beach fill equilibration on the nearshore hardbottom and adjacent habitats over an 18-month period following completion of construction. This 18-Month Post-Construction Nearshore Environmental Monitoring Report present the results of this monitoring. The principal question addressed in this report is:

Were there quantifiable, negative, secondary impacts to the nearshore habitat as a result of construction of Segment III of the Broward County Shore Protection Project?

Several main hypotheses were formulated to address topics of special concern, including: hardbottom burial, impacts to stony coral abundance, and impacts to algal abundance - primarily those species known to be consumed by sea turtles. These hypotheses are as follows:

1. The pre-construction distance between MLW and the nearshore hardbottom edge is indistinguishable from the post-construction distance between MLW and the nearshore hardbottom edge.
2. The pre-construction abundance of substrate covered by sand and sediment depths on the experimental transects is indistinguishable from post-construction abundance of substrate covered by sand on the experimental transects.
3. The post-construction distribution of substrate covered by sand and sediment depths between control and experimental transects is indistinguishable from the pre-construction distribution of substrate covered by sand between control and experimental transects.
4. Pre-construction abundance of preferred macroalgae food items for juvenile green sea turtles on the experimental transects is indistinguishable from post-construction abundance of preferred macroalgae food items for juvenile green sea turtles on the experimental transects.
5. The post-construction distribution of preferred macroalgae food items for juvenile green sea turtles between control and experimental transects is indistinguishable from the pre-construction distribution of preferred macroalgae food items for juvenile green sea turtles between control and experimental transects.
6. The pre-construction abundance of stony corals on the experimental transects is indistinguishable from post-construction abundance of stony corals on the experimental transects.

7. The post-construction distribution of stony corals between control and experimental transects is indistinguishable from the pre-construction distribution of stony corals between control and experimental transects.

Additionally, latent and long-term (up to 18 months post-construction) effects of beach construction are addressed through supplementary functional group and species level examinations of community changes, as well as coral fate-tracking and stress indicators.

3.0 PHYSICAL DYNAMICS

3.1 Weather Conditions

Florida was impacted by four hurricanes during the 2004 hurricane season. Of the four storms, two, Hurricane Frances (5 September 2004) and Hurricane Jeanne (26 September 2004), had direct effects on the Southeast Florida coast including minor impacts to Broward County. This weather activity occurred in the pre-construction phase of the Shore Protection Project.

In 2005, during construction of the Hollywood/Hallandale/Dania (HHD) portion of the Segment III project, there were eight (8) coastal weather events that significantly affected the Broward County shoreline. The HHD project reach was constructed between 15 May and 4 November 2005. These eight storm events included the following:

- 10-12 June 2005 Weather event resulting in construction delay
- 10 July 2005 Hurricane Dennis
- 25 August 2005 Hurricane Katrina
- 6-10 September 2005 Hurricane Ophelia
- 24 September 2005 Hurricane Rita
- 5 October 2005 Nor'easter
- 23 October 2005 Hurricane Wilma
- 1 November 2005 Nor'easter

Each of these events caused weather delays during project construction. During four of the hurricanes, the trailing suction (TS) hopper-dredge was forced to demobilize from the Broward County offshore waters to a remote location.

The tracks of the five hurricanes that affected the Broward County coastline during project construction are depicted in Figure 3. A time-series of offshore wave heights, as represented by a wave hindcast for the 2005 hurricane season, is presented in Figure 4. The hindcast wave height record indicates the magnitude and frequency of elevated wave heights offshore of the Broward County coast during construction of the Segment III project. The individual magnitude of wave heights during the hurricanes as well as total wave energy offshore of Broward County during the 2005 hurricane season were above average and in the case of Hurricanes Dennis, Katrina, and Wilma were extreme compared to typical conditions.

Figure 5 depicts the alongshore extent of completed sections of the Segment III beach fill at the time of occurrence of each hurricane during the 2005 season. The graphic indicates the areas of

constructed beach fill that were affected by the respective hurricanes. For example, the reach of shoreline between R-120 and R-126 was completed prior to the occurrence of Hurricane Dennis in July 2005 and, therefore, the beach fill in this area was exposed to the effects of all five hurricanes during 2005. Conversely, the beach fill along the northern end of HHD was not completed until after the passage of Hurricane Rita and therefore was only exposed to the conditions associated with Hurricane Wilma. All reaches of the HHD project beach fill were exposed to at least one of the hurricanes in 2005 immediately following fill placement. Construction of the John U. Lloyd (JUL) project reach did not begin until after the 2005 hurricane season and was therefore not exposed to extreme wave conditions following placement of sand fill.

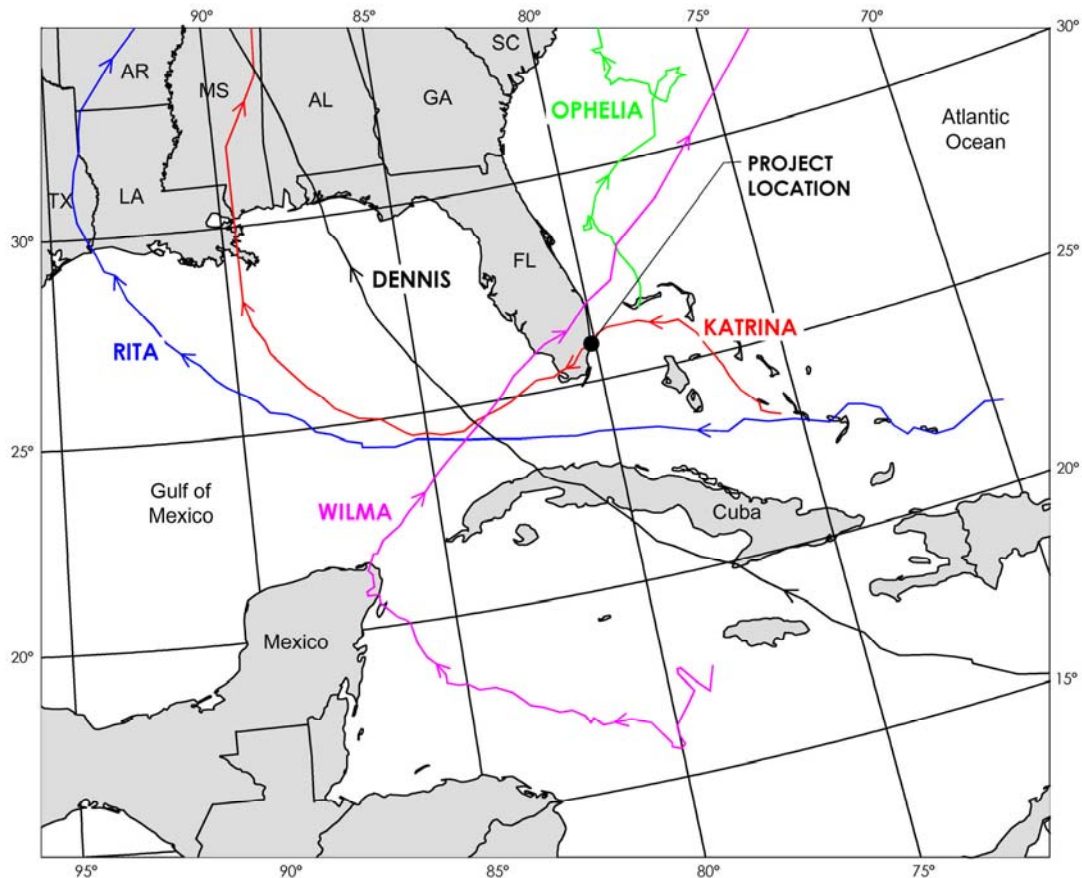


Figure 3. Graphical summary of the five 2005 hurricanes that affected Broward County.

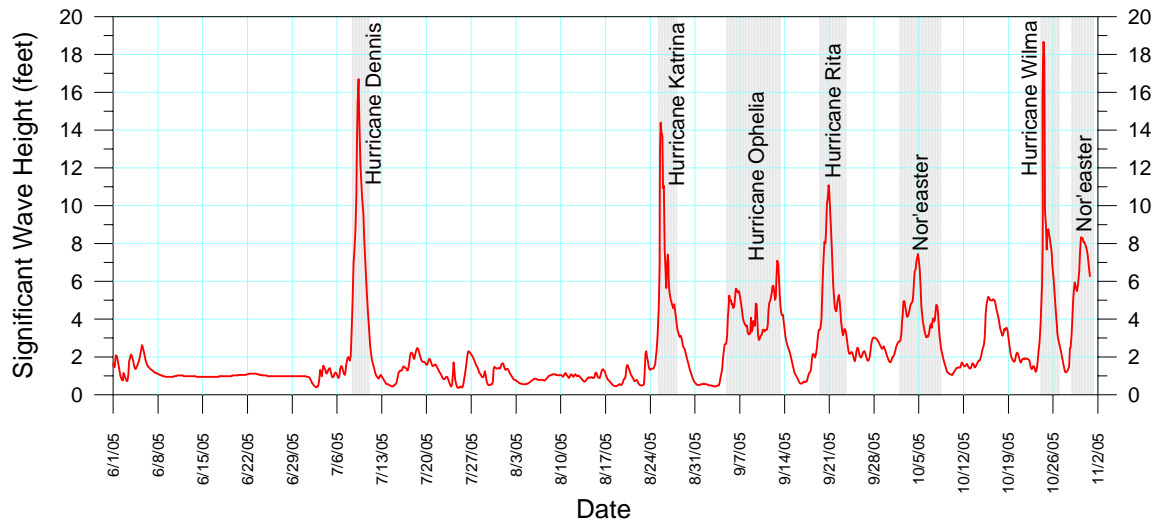


Figure 4. Hindcast wave conditions offshore of Broward County, Florida for June through November 2005.

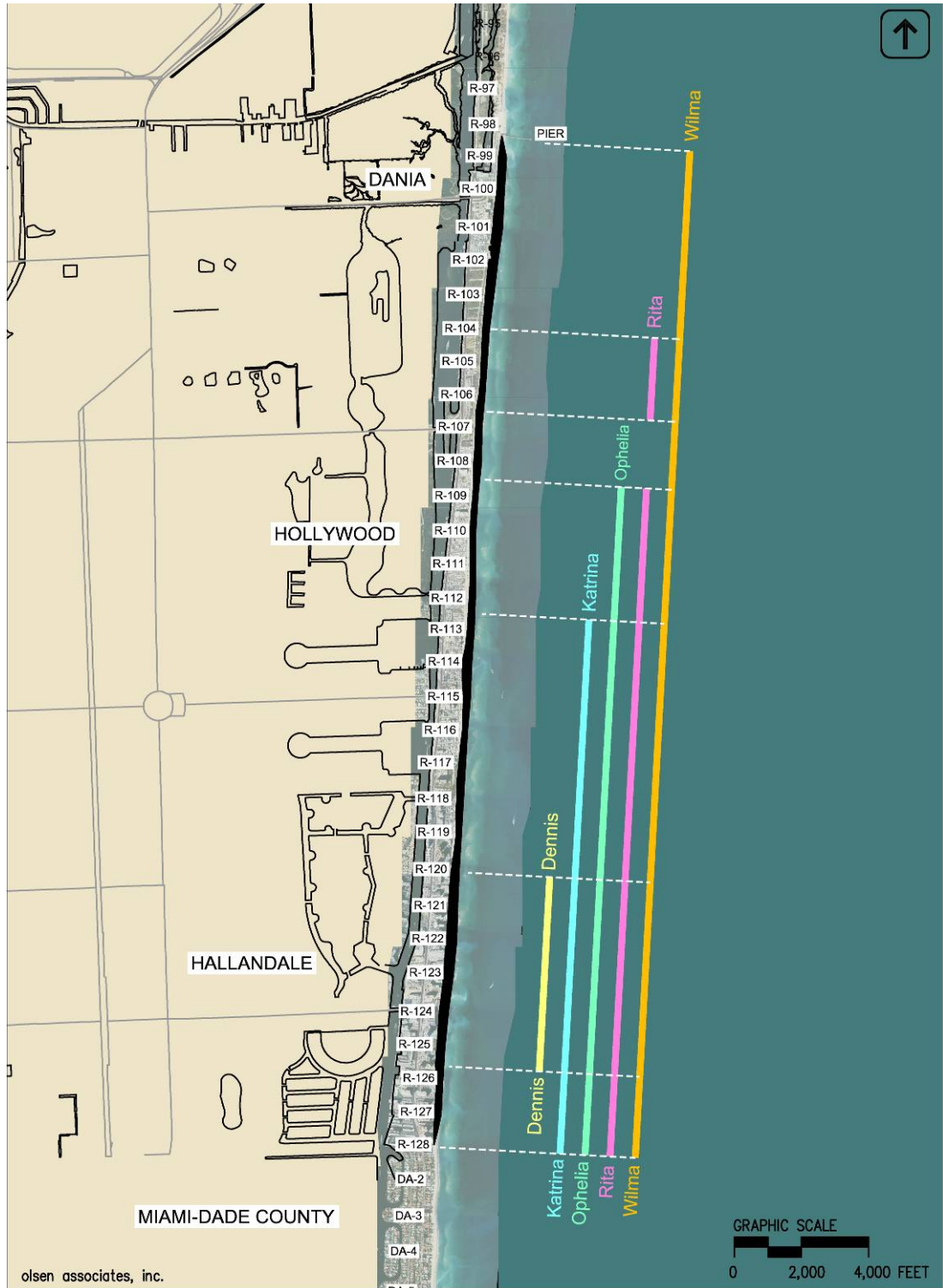


Figure 5. The colored lines represent the alongshore location and extent of completed sections of beach fill in Hollywood/Hallandale/Dania at the time of occurrence of the 2005 hurricanes. For example, the portion of the beach fill project constructed between R-120 and R-126 was exposed to the effects of Hurricanes Dennis, Katrina, Ophelia, Rita, and Wilma as well as the two significant nor'easter events.

3.2 Hardbottom Edge

The sand/nearshore hardbottom boundary, or nearshore edge, along the Segment III shoreline and northern Miami-Dade County, 47,500 feet or approximately 9 miles in length, was mapped in detail before and after construction of the Segment III, Shore Protection Project to evaluate possible project-related changes to its location, and to ascertain whether quantitative predictions of hardbottom coverage were validated by events. December 2001 and April/October 2005 surveys represent pre-project conditions. The April 2006 and July 2007 represent immediate post-construction and 17-month post-construction conditions, respectively (Figure 6).

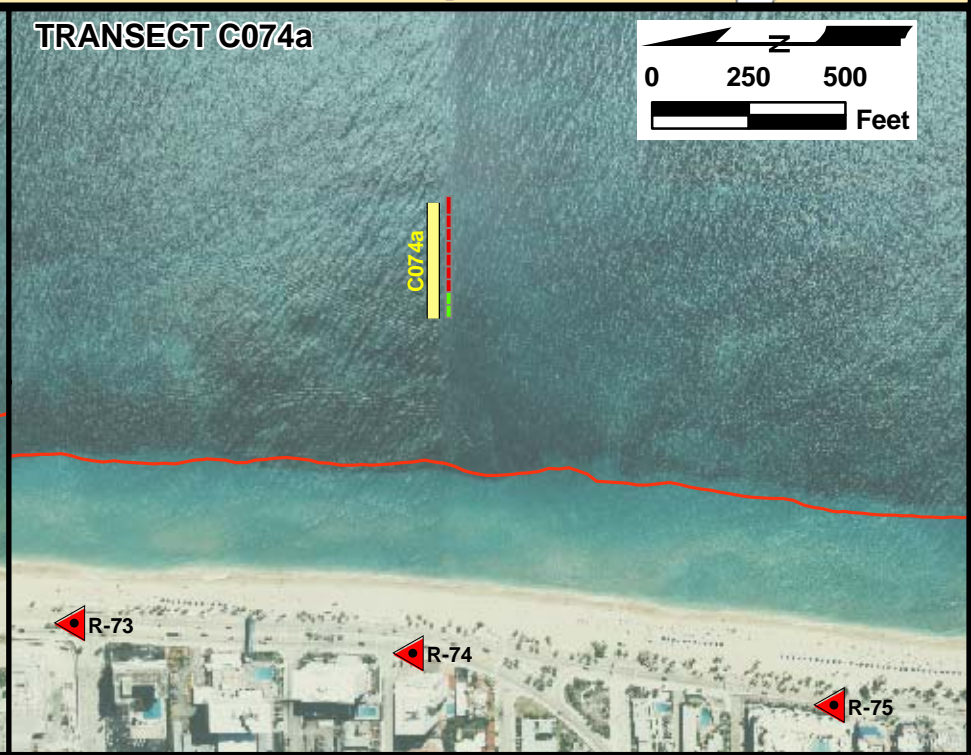
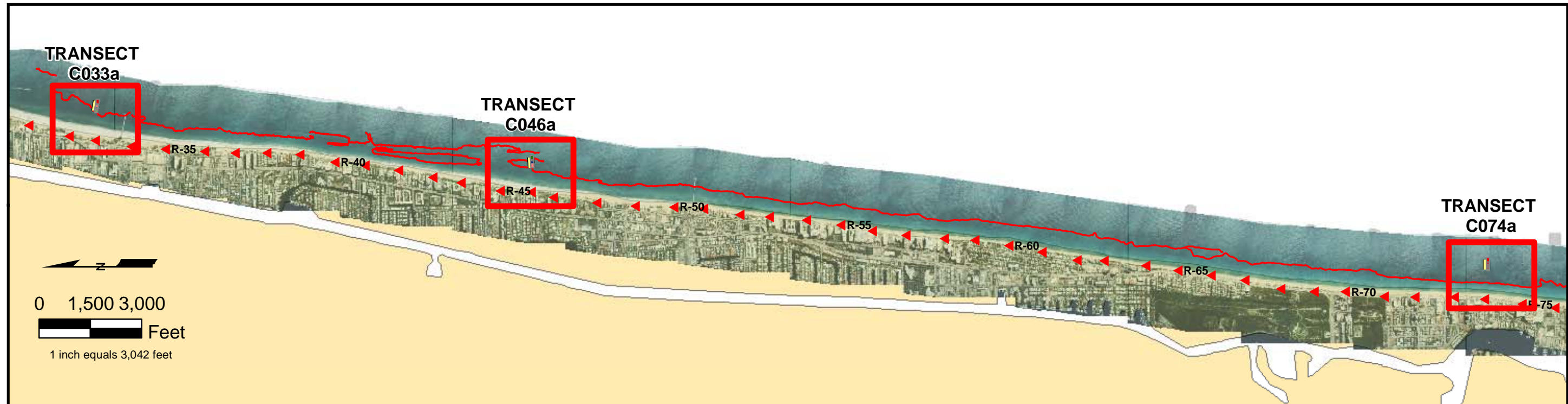
Changes in the location of the nearshore edge and areas of coverage and exposure were computed through comparison of the respective surveys for four periods (Figure 7). The periods include (1) the pre-project period from December 2001 to April/October 2005; (2) the project construction period from April/October 2005 to April 2006; (3) the project construction period and post-construction period from April 2006 to July 2007; and (4) the total period represented by detailed survey from December 2001 to July 2007.

Comparison of all the surveys indicates a wide range of nearshore hardbottom coverage and exposure occurrences *before* and *after* the project along the Segment III and northern Miami-Dade County shoreline.

Between 2001 and 2005 (pre-project period), along the entire 9 mile survey area, there was a net coverage of 4.03 acres of nearshore hardbottom. This net change was the result of large gross changes in coverage and exposure, on the order of 65 acres. Along each of the two project reaches, however, net changes were more varied with 14.48 acres of hardbottom exposure due to consistent chronic erosion in JUL and 13.40 acres of net coverage in HHD. The net coverage in HHD during the pre-construction period was the result of large gross changes in coverage and exposure along the entire HHD shoreline (~34 acres). Some of these changes could have resulted from an unusually active 2004 hurricane season, during which the area was subject to the impacts of Hurricanes Francis and Jeanne.

During the survey period that included project construction (2005 to 2006), substantial changes in hardbottom coverage and exposure were documented along the entire 9 mile survey area. Along the entire surveyed area a total of 50.42 net acres of hardbottom were covered. Some of this coverage, however, occurred along areas outside the project limits. In the JUL project area, there was a net coverage of 18.02 acres of hardbottom. This included coverage of the 14.48 acres of hardbottom exposed at this location during the pre-construction period of 2001 and 2005. Along the HHD shoreline, 36.73 acres of net hardbottom coverage occurred over the 12-month period between April 2005 and April 2006. This was also the period during which the Broward County shoreline and various reaches of the HHD project were exposed to the effects of 5 hurricanes and 3 other significant coastal storm events during the summer of 2005. These weather events had a pronounced effect upon sediment transport conditions along the project shoreline.

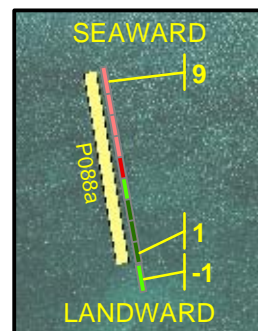
Between 2006 and 2007, the 17-month post-project period, more than 23 acres were re-exposed along the HHD shoreline. Only minor changes in hardbottom coverage occurred along the JUL



NOTES:

1. DATE OF AERIAL PHOTOGRAPHY: 04/07/07.
2. ARTIFICIAL REEF COORDINATES PROVIDED BY COASTAL SYSTEMS INTERNATIONAL, INC., 2003.
3. THE SERIES OF BLOCKS ALONG THE EXISTING 92 M TRANSECT (THICK YELLOW LINES) CORRESPOND TO 10 M SEGMENTS (#1=LANDWARD, #9=SEAWARD).
4. FIVE TRANSECTS (PO88A, PO90A, P100B, P101A, AND P116A) CONTAIN AN EXTRA 10 M SEGMENT (# -1) THAT RUNS LANDWARD FROM THE START OF THE WESTERNMOST SEGMENT OF EACH TRANSECT (# 1).
5. TEST RESULTS FOR O AND P TRANSECTS ARE BASED ON THE ABSOLUTE DIFFERENCE AND T-TEST (2 TAILED HETEROSCEDASTIC, SIGNIFICANT DIFFERENCES AT $\alpha \leq 0.05$) OF PRE AND FIRST MID-CONSTRUCTION VS. 16 - 18 MONTH POST CONSTRUCTION SEDIMENT DEPTH .
6. 2001 HARDBOTTOM SURVEY CONDUCTED BY CPE.

SEE NOTES 3 & 4

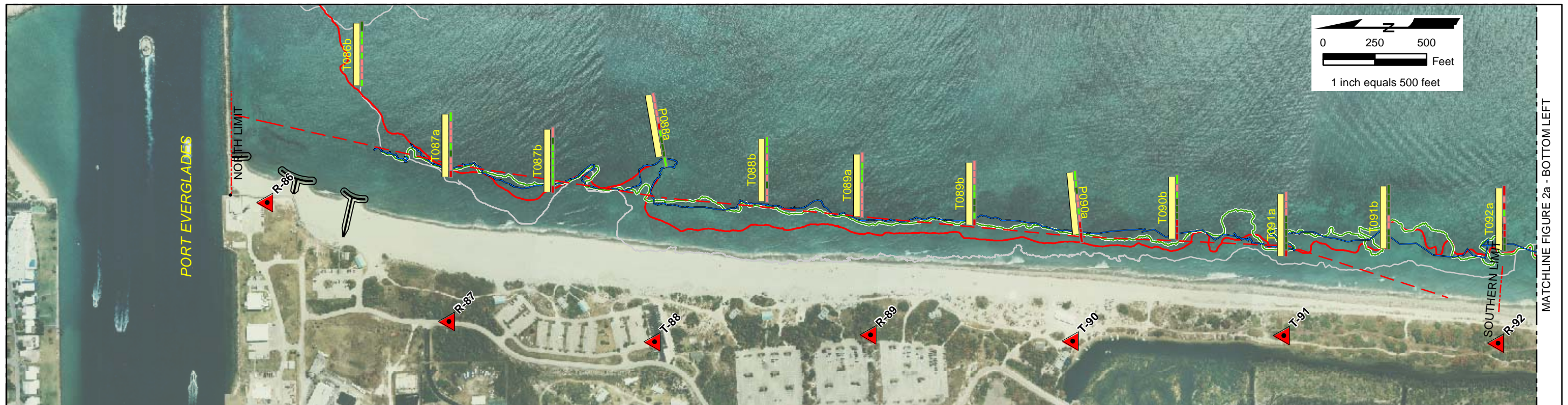


LEGEND:

- SEDIMENT DEPTHS SURVEY RESULTS - SEE NOTES 3, 4 & 5
- SIGNIFICANT INCREASE
 - INCREASE
 - NO CHANGE
 - DECREASE
 - SIGNIFICANT DECREASE
 - 92 METER TRANSECT
 - ~ 2001 HARDBOTTOM EDGE
 - ▲ FDEP MONUMENTS

TITLE:	BROWARD COUNTY SEGMENT III 18 MONTH CHANGE IN SEDIMENT DEPTH/HARDBOTTOM EDGE
	COASTAL PLANNING & ENGINEERING, INC 2481 NW BOCA RATON BLVD. BOCA RATON, FL 33431 PH. (561) 391-8102 FAX.(561) 391-9116

Date: 10/31/07	By: HMV	COMM NO: 5353.24	FIGURE 6a
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MATCHLINE FIGURE 2a - BOTTOM LEFT

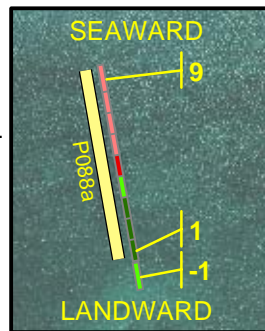


MATCHLINE FIGURE 2b - UPPER LEFT

NOTES:

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7. 2007, 2006, 2005, AND 2001 HARBOTTOM SURVEY CONDUCTED BY CPE.

SEE NOTES 3 & 4

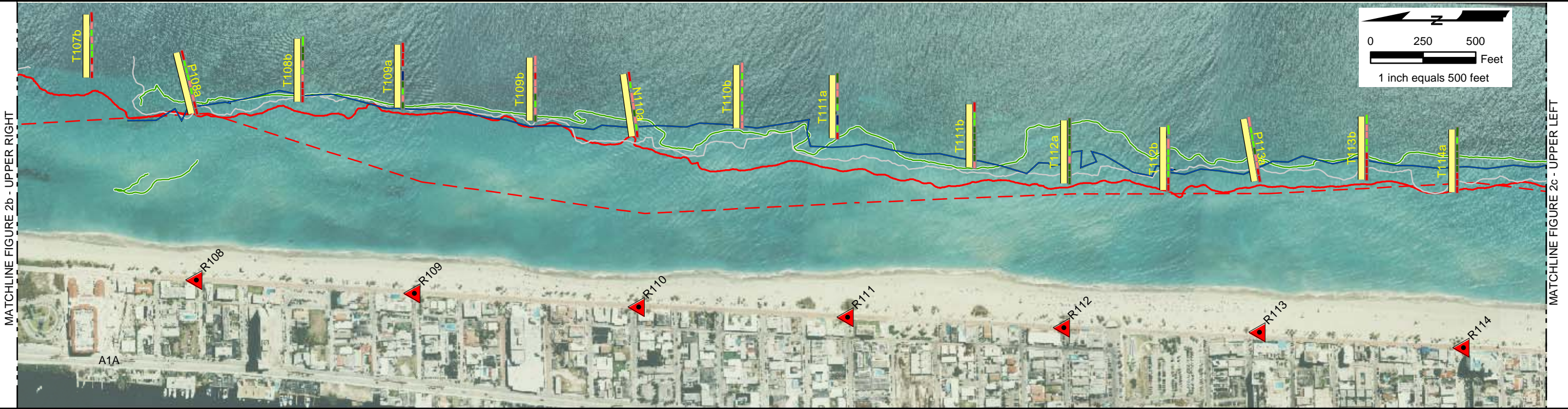
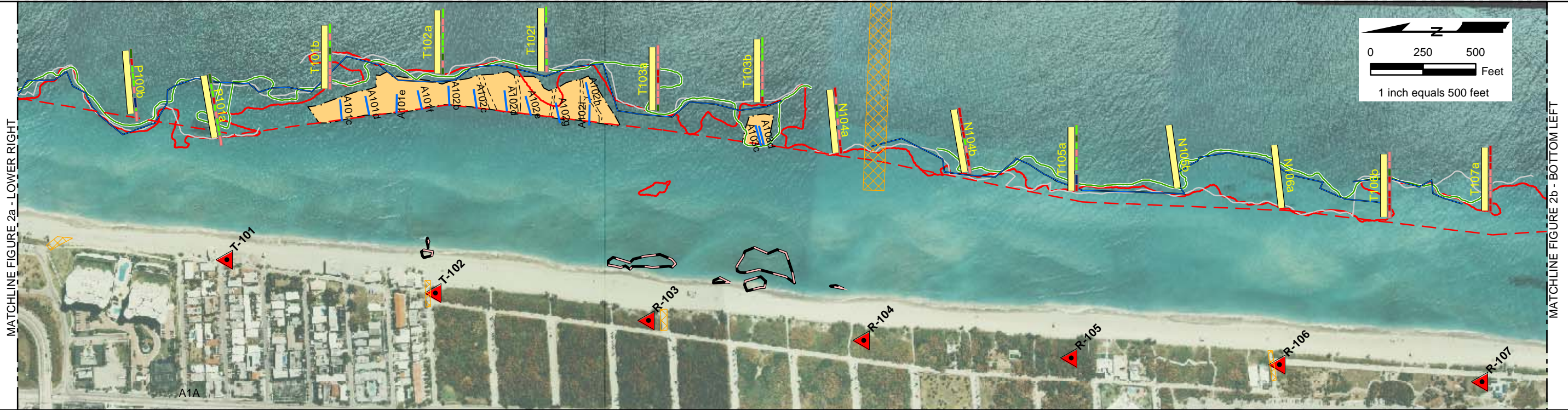


LEGEND:

- SEDIMENT DEPTHS SURVEY RESULTS - SEE NOTES 3, 4 & 5
- SIGNIFICANT INCREASE
 - INCREASE
 - NO CHANGE
 - DECREASE
 - SIGNIFICANT DECREASE
 - 92 METER TRANSECT
 - ESTIMATED EQUILIBRIUM TOE OF FILL
 - 2007 HARBOTTOM EDGE
 - 2006 HARBOTTOM EDGE
 - APRIL/OCTOBER 2005 HARBOTTOM EDGE
 - 2001 HARBOTTOM EDGE
 - FDEP MONUMENTS

TITLE: **BROWARD COUNTY
SEGMENT III
18 MONTH
CHANGE IN SEDIMENT DEPTH/HARBOTTOM EDGE**

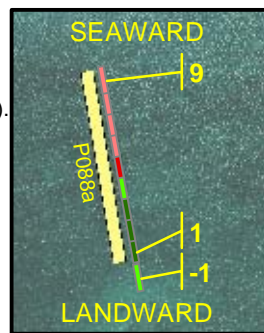
COASTAL PLANNING & ENGINEERING, INC
2481 NW BOCA RATON BLVD.
BOCA RATON, FL 33431
PH. (561) 391-8102
FAX.(561) 391-9116



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7. 2007, 2006, 2005, AND 2001 HARDBOTTOM SURVEY CONDUCTED BY CPE.

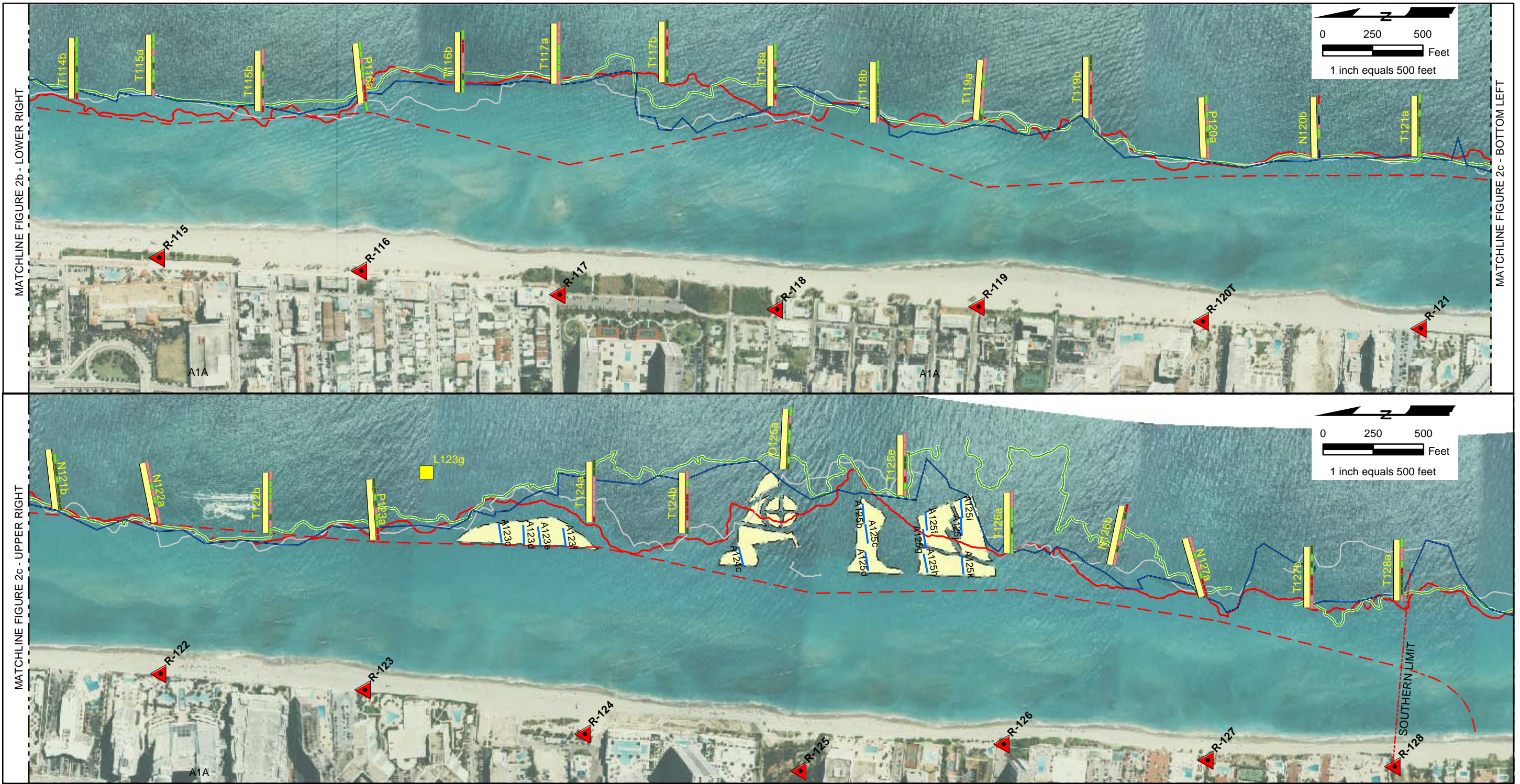
SEE NOTES 3 & 4



LEGEND:

- | | |
|---|-------------------------------------|
| SEDIMENT DEPTHS SURVEY RESULTS - SEE NOTES 3, 4 & 5 | ESTIMATED EQUILIBRIUM TOE OF FILL |
| SIGNIFICANT INCREASE | 2007 HARDBOTTOM EDGE |
| INCREASE | 2006 HARDBOTTOM EDGE |
| NO CHANGE | APRIL/OCTOBER 2005 HARDBOTTOM EDGE |
| DECREASE | 2001 HARDBOTTOM EDGE |
| SIGNIFICANT DECREASE | 2001 WORM ROCK LOCATION (MITIGATED) |
| 92 METER TRANSECT | ARTIFICIAL REEF AS-BUILT 7, 8 & 9 |
| | FDEP MONUMENTS |

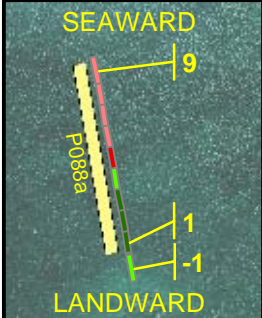
TITLE:		BROWARD COUNTY SEGMENT III 18 MONTH CHANGE IN SEDIMENT DEPTH/HARDBOTTOM EDGE	
		COASTAL PLANNING & ENGINEERING, INC	
		2481 NW BOCA RATON BLVD. BOCA RATON, FL 33431 PH. (561) 391-8102 FAX.(561) 391-9116	
Date: 10/31/07	By: HMV	COMM NO: 5353.24	FIGURE 6c



NOTES:

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7. 2007, 2006, 2005, AND 2001 HARDBOTTOM SURVEY CONDUCTED BY CPE.

SEE NOTES 3 & 4



LEGEND:

- | | |
|---|--------------------------------------|
| SEDIMENT DEPTHS SURVEY RESULTS - SEE NOTES 3, 4 & 5 | CORAL FATE TRACKING STATION |
| — SIGNIFICANT INCREASE | — ARTIFICIAL REEF AS-BUILT 10 & 11 |
| — INCREASE | — 2007 HARDBOTTOM EDGE |
| — NO CHANGE | — 2006 HARDBOTTOM EDGE |
| — DECREASE | — APRIL/OCTOBER 2005 HARDBOTTOM EDGE |
| — SIGNIFICANT DECREASE | — 2001 HARDBOTTOM EDGE |
| — 92 METER TRANSECT | — ESTIMATED EQUILIBRIUM TOE OF FILL |
| | ▲ FDEP MONUMENTS |

TITLE: **BROWARD COUNTY
SEGMENT III
18 MONTH
CHANGE IN SEDIMENT DEPTH/HARDBOTTOM EDGE**



COASTAL PLANNING & ENGINEERING, INC
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BOCA RATON, FL 33431
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Date: 10/31/07 By: HMV COMM NO: 5353.24 **FIGURE 6d**

shoreline over this period. These findings of coverage and re-exposure are consistent with the sediment depth and sediment percent cover results from individual transects. The trend of re-exposure is expected to continue. As the nearshore sand edge continues to adjust to the presence of the beach fill and to recover from the effects of the 2005 hurricane season, the nearshore hardbottom edge area is gradually returning to pre-construction conditions. These findings also confirm that observations at the biological transects are representative of the whole project area, and that no bias was introduced in the results of the sediment monitoring by site selection criteria.

As of April 2007, the net coverage of hardbottom along the JUL project reach was 4.93 acres relative to 2001 baseline conditions. Along the HHD shoreline, the total net hardbottom coverage, as computed through direct comparison of the 2001 and 2007 surveys, was 28.02 acres. Of this, 13.40 acres of hardbottom coverage occurred along the HHD shoreline during the 3.3 years immediately prior to project construction. Therefore, the net coverage of hardbottom along the HHD project shoreline since 2005 is 14.62 acres, as computed through direct comparison of the 2001 and 2007 surveys and consideration of change between 2001 and 2005. This indicates that the magnitude of hardbottom gains and losses that occurred from 2005 to 2007 (project and post-project) in HHD is generally equivalent to those that occurred from 2001 to 2005 (pre-project). Direct comparison of the 2001/2005 and 2005/2007 surveys, respectively, suggest that the magnitudes of pre- and post-project net hardbottom coverage/exposure change along the HHD project reach are identical.

It is of interest to note that about 5.5 acres of the documented post-2005 coverage in HHD -- computed through comparison of the 2005 and 2007 surveys --, more than 22 percent of the gross total hardbottom along that reach, occurred along a highly localized area (2.6 percent of the total HHD project length) around the southern mitigation area. This coverage is believed to be due to the local alteration of nearshore circulation in and around the mitigation structures, probably exacerbated by the high energy events during the 2005 hurricane season.

Exclusive of the documented coverage around the southern mitigation area as well as HHD project area pre-project changes, the net post-project nearshore hardbottom coverage along the HHD project shoreline as of April 2007 was 7.56 acres.

Prior to project construction, it was anticipated that fill equilibration would consist of a gradual migration of the nearshore edge and that full equilibration would be reached approximately three years following completion of project construction. It is now believed, however, that the storm conditions of 2005 (project construction period) may have drastically altered cross-shore and alongshore processes compared to those of "normal" weather conditions and typical beach fill equilibration processes. Further, these storm-induced seaward migrations of the nearshore edge are now seen to be recovering, resulting in a continuing trend of shoreward migration of the nearshore edge. Thus barring future significant storm impacts, it is likely that by three years post-construction, net hardbottom coverage will be in order-of-magnitude range of pre-project predictions.

The large pre-project variations in the nearshore hardbottom edge location make it difficult to conclude how much hardbottom coverage occurred due to the presence of the project or how

much would have occurred naturally under the influence of the significant weather events in 2005. It is intuitively evident that more sand in the system resulted in a more seaward translation of the sediment relative to pre-project conditions. Without the project, however, it is also intuitive (and noted in HHD between 2001 and 2005) that more hardbottom is exposed due to erosion, only to be covered by dynamic sand movement in high wave energy events. This is especially true along the HHD project reach, where the project shoreline and beach fill was affected by 5 hurricanes and several northeasters during the construction period, prior to the equilibration of the profile to a more storm-tolerant configuration. Accordingly, the three-year post construction nearshore edge survey is expected to more clearly reveal the long-term changes in nearshore edge conditions along the Segment III shoreline.

It is recommended that planning for future projects in Broward County evaluate natural nearshore edge fluctuations through comparison of multiple, possibly annual, nearshore edge surveys prior to project initiation. It is also important to consider shape, relief, and configuration details of the nearshore edge. A high resolution hydrographic survey using a system such as multi-beam sonar would be required to map the area in sufficient detail.

It is also recommended that planning for siting and configuration of future nearshore mitigative reefs consider the potential effect the structures may have upon nearshore circulation as well as the nearshore wave climate. Circulation patterns around the mitigation reefs in Segment III are believed to have contributed to unexpected temporary coverage of nearshore hardbottom near the Segment III mitigation areas.

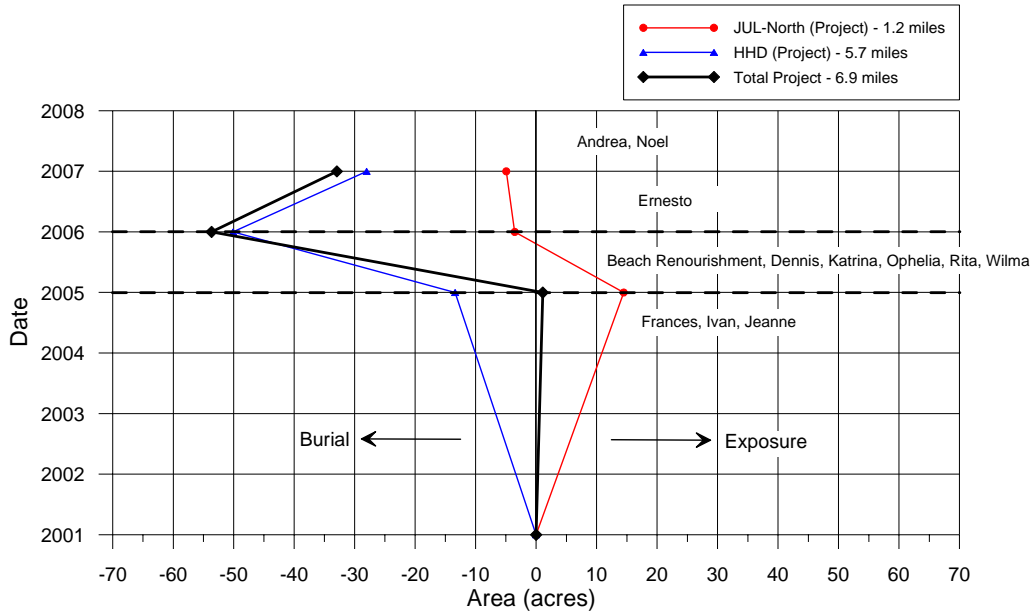


Figure 7. Temporal change in nearshore hardbottom area for the JUL and HHD project reaches. On a per unit length of shoreline basis, the changes in JUL and HHD are on the same order of magnitude.

3.3 Sediment Depth

Distinguishing the magnitude of project related impact from natural environmental fluctuations is increasingly difficult when abnormal weather patterns occur, as with the hurricane season South Florida experienced in 2005. However, with the appropriate environmental monitoring plan, determinations regarding project-related impacts can still be made with a reasonable level of confidence.

Figure 6 provides detailed sediment accumulation and erosion results for every 10 meters of every transect. The 2005 hurricane season had an equal effect on control and experimental sites, adding approximately 30 mm to the mean sediment depths in the 0-30 meters (Figure 8). Sediment depth increased at the experimental sites by another 30 mm during the 0-2 Post and 6-8 Post-construction time periods. The last three monitoring periods (9-12 Post, 14-15 Post, and 16-18 Post) show sediment depth at the experimental sites has decreased to mid-construction levels. Control sites continually decreased until a significant drop in 9-12 Post and 13-15 Post. The controls experienced a 22 mm increase in sediment depth during the 16-18 Post monitoring event. This sharp increase is a result of transect C098a's relative location to the hardbottom edge (See Figure 6b) and low relief along the hardbottom edge. Both characteristics combine to form an area that is susceptible to large increases in sediment depth and sediment coverage as result of relatively low-volume sand migrations.

These results show that beach nourishment had a statistically significant impact on sediment depth beyond the predicted ETOF in the 0-30 meters after 2005 hurricane season disturbances. Control and experimental sediment depths increased similarly during 2005 hurricane season and then the experimental sites significantly deviated from control sediment depths in the following monitoring events; this is a clear indication of project related sediment accumulation. However,

the burial that occurred in the 0-30 meters was temporary. By 16-18 months post-construction, the sediment depth had returned to mid-construction levels and there was no significant difference between the control and experimental sites.

Determining 2005 hurricane season and project related impact is slightly more difficult for the 31-92 meters because control and experimental sediment depths had different starting conditions (Figure 8). However, like the 0-30 meter dataset, it appears sediment accumulation related to 2005 hurricane season at the control sites was realized during the mid-construction monitoring, a period which included impacts from Hurricanes Dennis and Katrina. Assuming that this is true for the experimental transects as well, the significant increases in sediment depth during 0-2 Post and 3-5 Post should be attributed to beach nourishment. Unlike the 0-30 meter sediment depths, the 31-92 meter sediment depths have remained elevated through 18 months post-construction.

This dataset provides insight into the sediment transport time scale that is associated with the Broward Shore Protection Project. Construction ended in February 2006 and the first signal of increased sediment depth at the 0-30 meters, not associated with the 2005 hurricane season, occurred during the next monitoring period, February-April 2006 (0-2 Post). This initial pulse of sediment can be further tracked by looking at the 31-92 meter data where it appears to be shifted by one sampling date group, or 3 months. This suggests that beach nourishment sediment took 0-3 months post-construction to reach the nearshore sand-hardbottom interface and 3-6 months before the 31-92 meters experienced the effects of nourishment. These time scales are most likely accelerated considering the anomalous wave energy recorded during mid-construction (see Figure 5).

Subdividing the nearshore 30 meters of sediment depth data into 10 meter groups provided further resolution into the sediment dynamics associated with beach construction (Figure 9). The 0-10 m and 11-20 m datasets experienced a mean increase of 60 mm; this is more than twice the accumulation recorded at the 21-30 m and 31-92 m areas of the transects. These results depict a directional movement of sediment from nearshore to offshore, with greater sediment accumulation occurring nearshore and gradually tapering to offshore areas.

Understanding the sediment dynamics associated with beach nourishment projects is essential in developing biological techniques that accurately track impacts resulting from these shoreline activities. This detailed analysis of sediment dynamics has revealed a pulse of sand movement from west to east that gradually tapers to offshore areas, with temporary, high-level sediment accumulation occurring on the nearshore edge of the hardbottom and more persistent, low-level sand accumulation occurring on the hardbottom areas further offshore. These findings have significant implications in determining habitat areas that will be impacted by nourishment activities and how long impact conditions are expected to last in those specified habitats. The results of this sediment analysis show elevated sediment levels related to project activities extend beyond the first 30 meters of hardbottom; therefore, future biological monitoring plans designed to track nourishment impacts should extend beyond the first 30 meters of hardbottom.

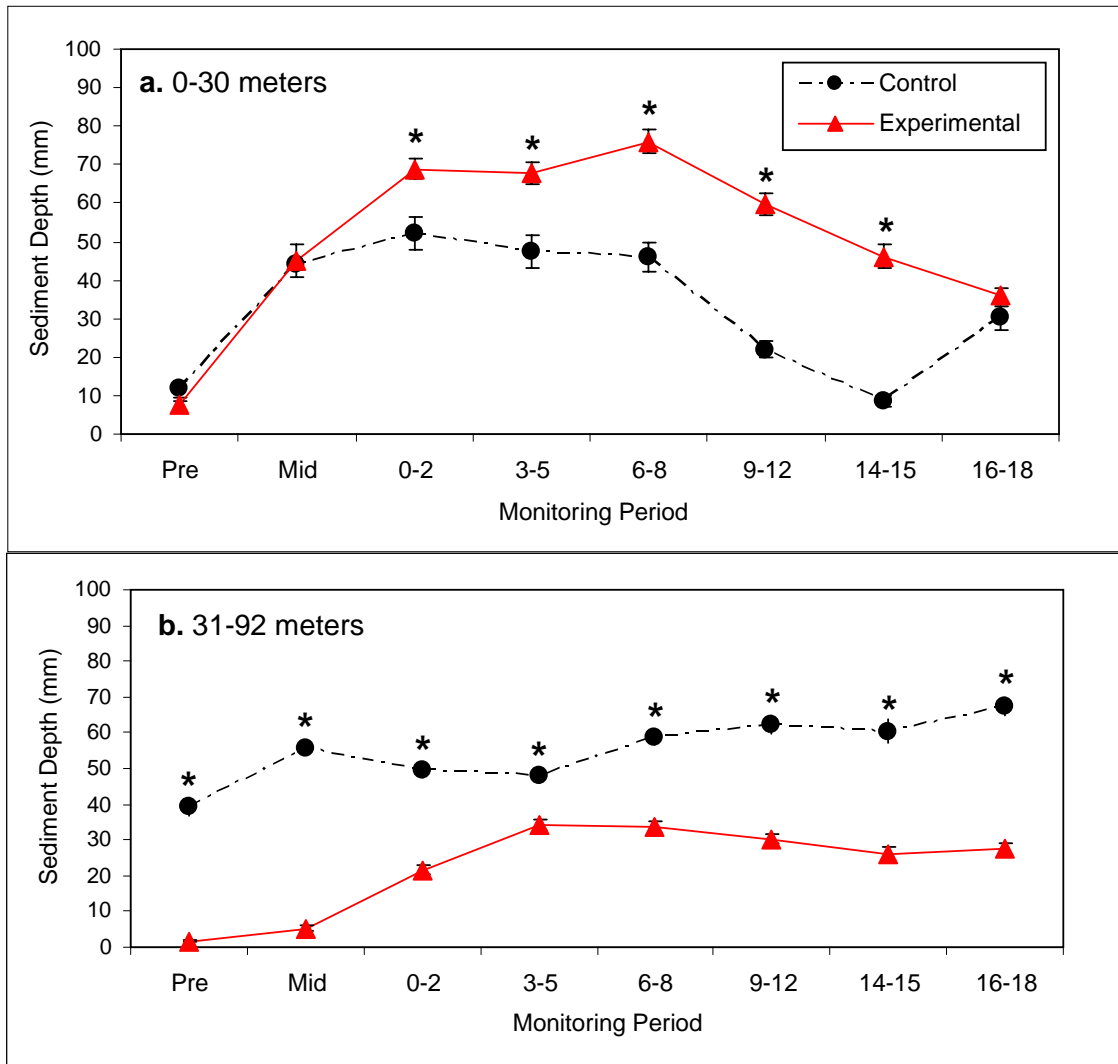


Figure 8. **a.** 0-30 m and **b.** 31-92 m mean sediment depths (mm) for control and experimental transects with standard error bars for eight monitoring periods. Significant differences ($\alpha = 0.05$) in percent cover are indicated by an asterisk (*).

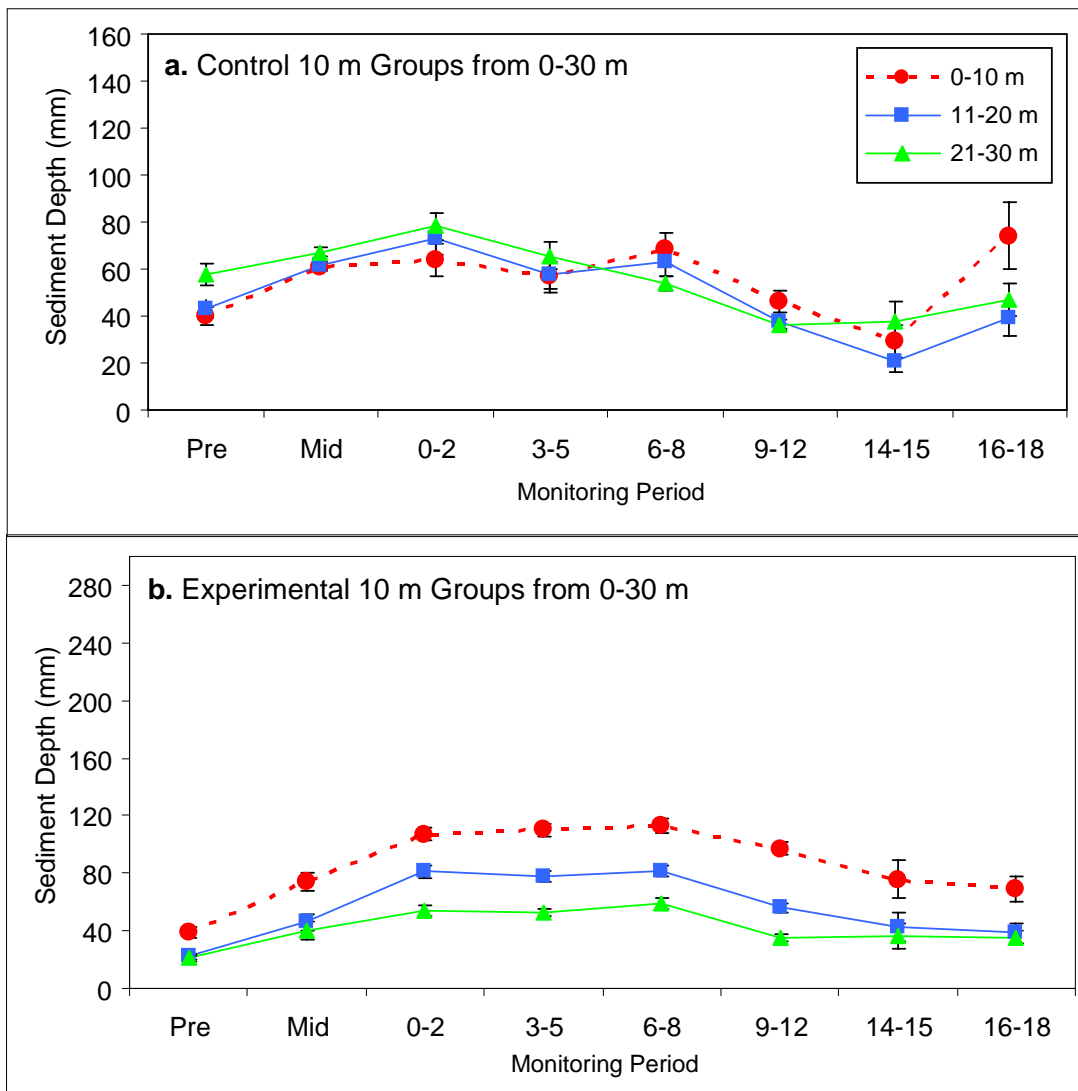


Figure 9. Mean sediment depths (mm) with standard error bars for the 10-m groups from 0-30 meters at the **a.** control and **b.** experimental transects for eight monitoring periods.

3.4 Probability of Hardbottom Burial

Each transect was divided into two zones, 0-15 m (*near*) and 17.5-30 m (*far*) in order to examine differences in sediment coverage in relation to distance from the hardbottom edge. A logistic, multivariate regression was run to test for significant differences in the probability of complete hardbottom burial (*i.e.*, 100% sediment cover) among BEAMR quadrats based on the designated transect zone and site type (control and experimental) over time. Quadrats that exhibited 100% sediment cover in any given assessment were coded as one (1), and all other relative sediment cover values were coded as zero (0). Predictors were added as bivariate indicator variables and main effects were allowed to interact with time by adding cross-product terms to the model. This allowed between-site type comparisons at each monitoring period. Significant predictors ($\alpha = 0.05$) were assessed from Wald chi-square statistics and asymptotic standard errors (Table 2).

Prior to construction the probability of observing 100% hardbottom burial in BEAMR quadrats was similar between site types. Both site types experienced increases in the probability of hardbottom burial following the beginning of nourishment construction (monitored mid-construction), regardless of zone (Figures 10a and 10b); however, these effects appear to have been at least 1.5 times greater with the influence of major storm events during the 2005 hurricane season. While the probability of hardbottom burial in control areas peaked in the mid-construction monitoring event and diminished through time, *near* and *far* experimental burial probability increased into the 0-2 months post-construction time period. Furthermore, *near* experimental zones had a much greater probability of exhibiting hardbottom burial than *near* control zones (Figure 10a). Through time, however, the probability of observing total hardbottom burial has diminished, and both zones on the experimental transects are comparable to that of the control transects.

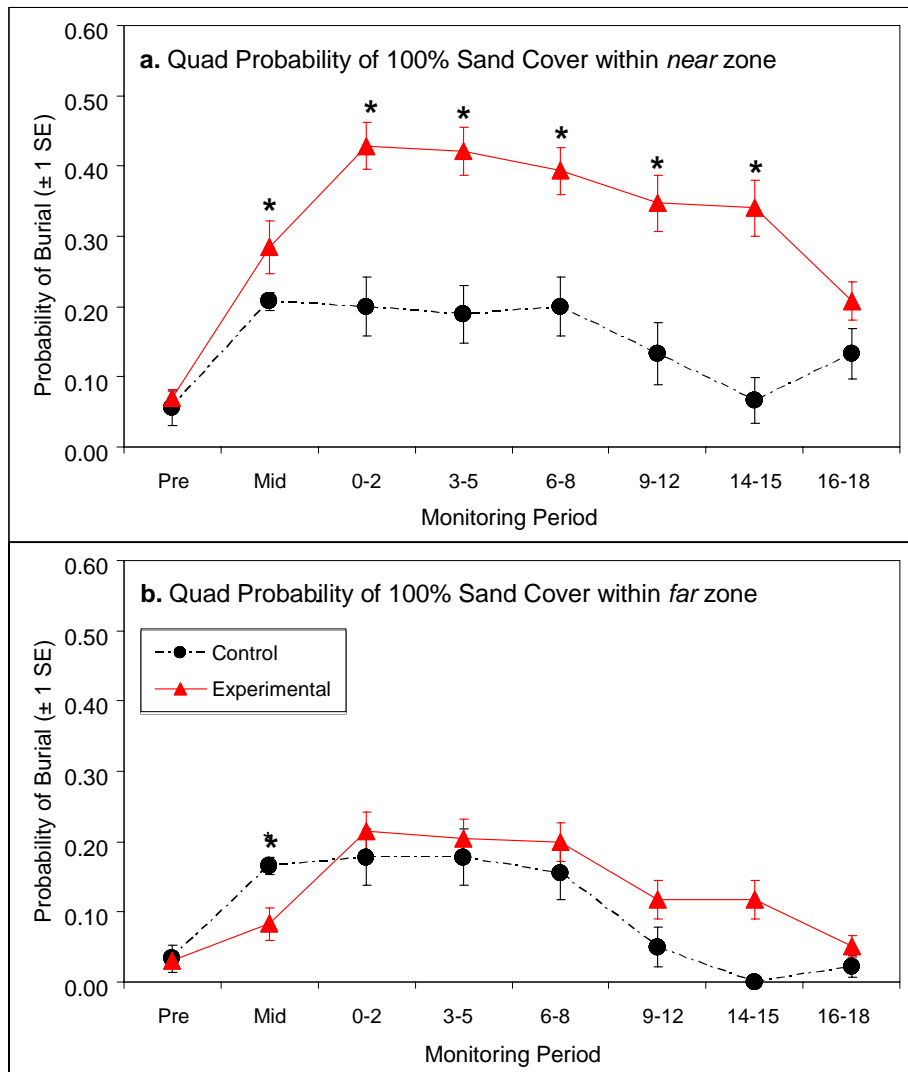


Figure 10. Temporal trends in the probability of observing complete hardbottom burial on control and experimental treatments among BEAMR quadrats grouped by **a.** *near* (0-15 m) and **b.** *far* (17.5-30 m) zones. Significant differences ($\alpha = 0.05$) in percent cover are indicated by an asterisk (*).

Table 2. Probability estimates of total hardbottom burial among BEAMR quadrats grouped by zone and site type (e.g., *Near* CONTROL), and the accompanying monitoring period, sample size (n), standard error (SE), and logistic regression Wald chi-square based probability of statistical significance (*p*).

Time	<i>Near</i> CONTROL	n	SE	<i>Near</i> EXPERIMENTAL	N	SE	<i>p</i>
Pre-construction	0.06	90	0.02	0.07	432	0.03	0.63
Mid-construction	0.21	989	0.01	0.28	144	0.06	0.04
0-2 Post	0.20	90	0.04	0.43	216	0.03	0.00
3-5 Post	0.19	90	0.04	0.42	216	0.03	0.00
6-8 Post	0.20	90	0.04	0.39	216	0.03	0.00
9-12 Post	0.13	60	0.04	0.35	144	0.04	0.00
14-15 Post	0.07	60	0.03	0.34	144	0.04	0.00
16-18 Post	0.13	90	0.04	0.21	216	0.03	0.13
Time	<i>Far</i> CONTROL	n	SE	<i>Far</i> EXPERIMENTAL	N	SE	<i>p</i>
Pre-construction	0.03	90	0.02	0.03	431	0.01	0.87
Mid-construction	0.16	990	0.01	0.08	144	0.02	0.01
0-2 Post	0.18	90	0.04	0.21	210	0.03	0.47
3-5 Post	0.18	90	0.04	0.20	215	0.03	0.59
6-8 Post	0.16	90	0.04	0.20	216	0.03	0.37
9-12 Post	0.05	60	0.03	0.12	144	0.03	0.14
14-15 Post	0.00	60	0.00	0.12	144	0.03	-
16-18 Post	0.02	90	0.02	0.05	215	0.02	0.26

3.5 Turbidity

Results of turbidity monitoring during the eighteen months following completion of the Broward Segment III beach nourishment project indicate there are no project-related effects discernable from natural conditions, and that turbidity levels in all control and compliance sites remained relatively low throughout post-construction monitoring; turbidity measurements ranged from 0.07 to 1.82 NTUs in the control sites, and ranged from 0.03 to 4.12 NTUs in the compliance sites.

4.0 BIOLOGICAL DYNAMICS

4.1 Benthic Ecological Assessment for Marginal Reefs (BEAMR)

BEAMR was developed specifically for marginal reefs as opposed to ‘classic’ coral reefs. Marginal reefs describe coral reefs and coral communities that occur either close to environmental thresholds for coral survival or in areas characterized by “sub-optimal” or fluctuating environmental conditions (Perry and Larcombe, 2003). Key habitat quality indicators of marginal reefs are not well known because each habitat is subject to such variations in physical and biological characteristics; this forced an abandonment of reliance on indicator organisms in the design of BEAMR. Instead BEAMR measures everything visible from a birds eye view above the quadrat and pools organisms by functional group (sessile only). This generalization allows BEAMR to be efficient on any marginal reef. Macroalgae and coral are further broken down to genus and species and physical parameters, relief and sediment depth, are also measured. BEAMR is a non-consumptive survey and is, therefore, constrained to visually conspicuous organisms.

BEAMR Functional Groups

Non-parametric multivariate analyses were applied to the functional group data to determine if significant differences ($\alpha = 0.05$) existed temporally and spatially in the nearshore 30 meters of hardbottom habitat. The MDS ordination in Figure 11a takes into account all control (C) and experimental transects (O, P). It is defined by the factor *construction phase* (pre-, mid-, and post-construction) in order to present a picture of transect similarity in relation to the phase of beach construction. Figure 11b is the same MDS ordination as Figure 11a with the application of a 2-dimensional bubble plot defined by the variable *sediment cover*; the larger the bubble, the higher the average percent cover of sediment for that transect at a specific monitoring event. The bubble plot presents how sand cover influenced transect similarity. Further examination of the biotic community on the experimental transects revealed that the strongest differences between monitoring periods occurred between pre-construction and all subsequent events. This timeframe coincides with the 2005 hurricane season; however, natural sand movement was differentiated from project related sand cover by comparing the experimental area to the control area.

A second-stage community analysis was applied to the biotic dataset to compare the time-series at each transect, which were previously designated as a control or experimental transect type. If the temporal pattern between transect types could be differentiated, it would imply that a localized variable, such as beach construction, had affected one type and not the other regarding

functional group cover. The results indicated that the transect types could not be significantly differentiated and follow a similar temporal pattern (Figure 12). This leads to the conclusion that, when direct burial effects are excluded, beach construction did not change the temporal pattern of the experimental transects enough to have a significant effect on biotic functional group cover compared to the control transects.

Each experimental transect was examined independently to determine change in the biotic benthic community over time. Table 3 displays the percent similarity between pre-construction conditions (average of 8-pre and 2-pre) to 0-Post, 6-Post, 12-Post, and 18-Post for all experimental transects based on Cluster analysis with Similarity Profile (SIMPROF). The biotic benthic community on six of the twelve experimental transects could not be significantly differentiated from pre-construction conditions by 18 months post-construction; the other six remained significantly different.

Based on these analyses, it can be concluded that increased sediment cover adversely affected the functional group-level of the benthic community; however, since the final impact of fill equilibrium will not be determined until 36-month post-construction, the present state of the benthic community could be considered progressively recovering.

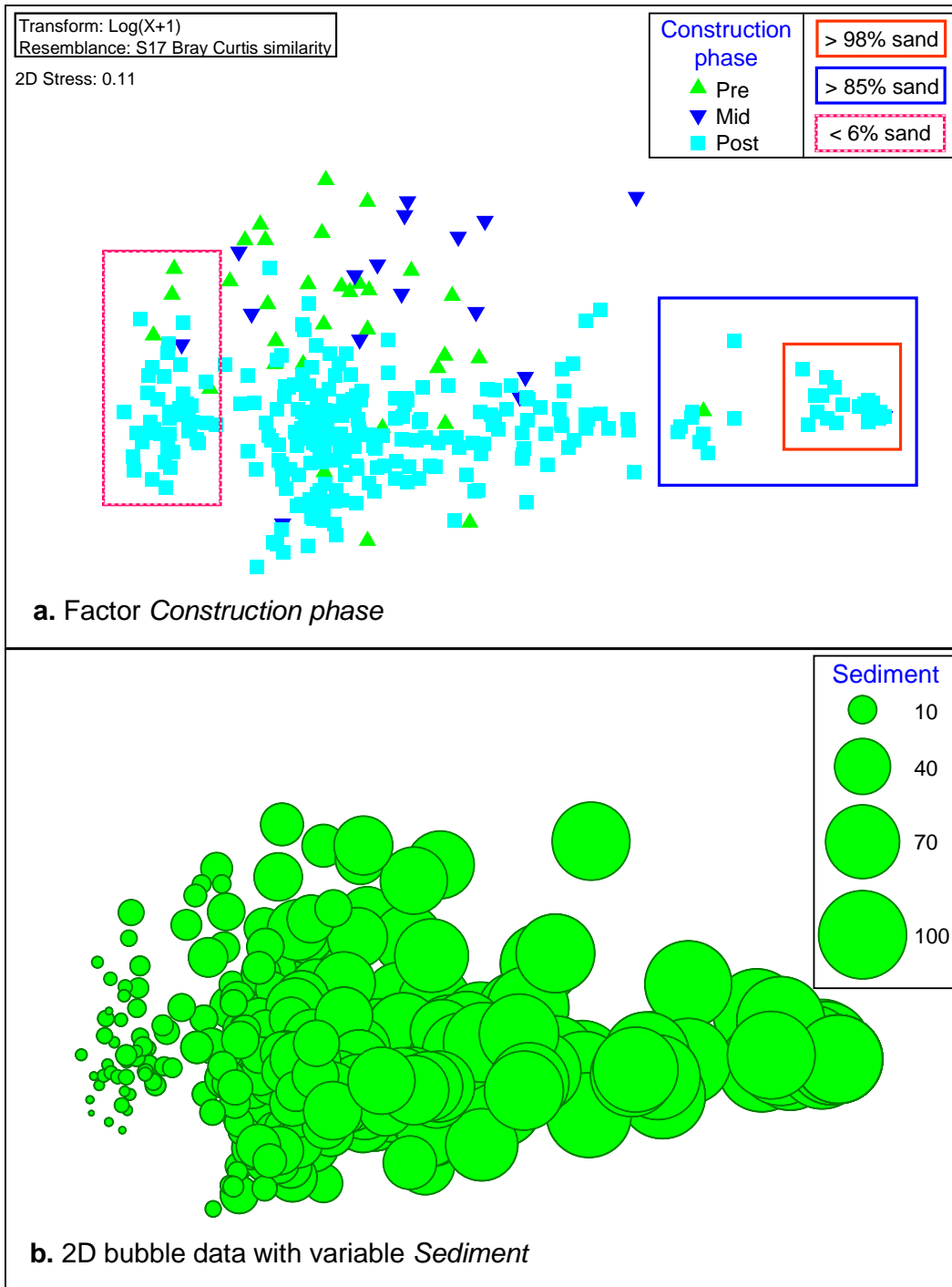


Figure 11. MDS ordination of all C, O, and P transects monitored between 8-month pre-construction and 18-month post-construction monitoring events defined by **a.** beach construction phase and **b.** a 2-dimensional bubble plot by the variable *sediment*.

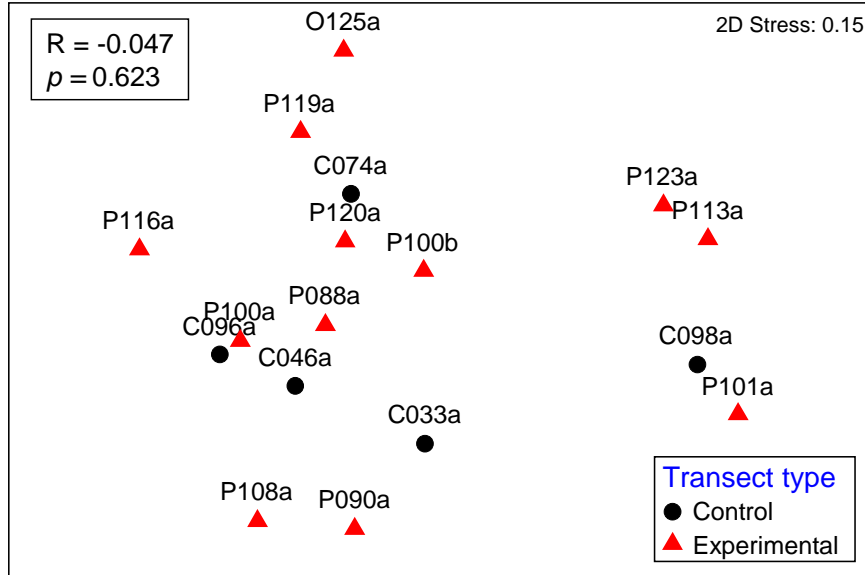


Figure 12. Second-stage MDS ordination and ANOSIM results (R and p -values) showing that significant differences in temporal pattern do not exist between control and experimental transect types based on functional group biotic data.

Transect	Similarity to Pre-Construction Community			
	0-Post	6-Post	12-Post	18-Post
P088a	68%	68%	68%	68%
P090a	76%	76%	76%	76%
P100a	73%	73%	73%	73%
P100b	81%	81%	81%	81%
P101a	16%*	38%	67%	67%
P108a	73%	73%	73%	73%
P113a	33%	63%†	63%‡	63%
P116a	71%	71%	71%	71%
P119a	74%	83%	83%	83%
P120a	80%	88%	85%	85%
P123a	32%	32%	83%	83%
O125a	86%	86%	91%	86%

Table 3. Percent similarity between pre-construction and the 0-, 6-, 12-, and 18-month post-construction monitoring events of the biotic benthic community for each experimental transect. *1-Post, †7-Post, and ‡15-Post substituted because no biotic data available at designated event. Significant differences ($\alpha = 0.05$) are highlighted.

BEAMR Macroalgae

A number of the macroalgae genera recorded along the experimental and control transects are primary foraging sources for juvenile green sea turtles (*Chelonia mydas*). Makowski *et al.* (2006) studied macroalgae species that are common to the diet of *C. mydas* in the nearshore waters of

Palm Beach, Florida by examining collected lavage samples. Eleven genera were reported: *Gracilaria*, *Acanthophora*, *Dictyota*, *Dictyopteris*, *Siphonocladus*, *Jania*, *Dasycladus*, *Cladophora*, *Bryothamnion*, *Rhizoclonium*, and *Enteromorpha*. Genera *Hypnea*, *Bryothamnion*, and *Gracilaria* were also noted by Wershoven and Wershoven (1988, 1992) to be preferred food items of *C. mydas* at John U. Lloyd State Recreation Area. Of the fourteen reported genera, seven were recorded during our monitoring: *Acanthophora*, *Bryothamnion*, *Dasycladus*, *Dictyota*, *Gracilaria*, *Hypnea*, and *Jania*. Although *C. mydas* has been shown to prefer certain genera of macroalgae, they have also been shown to be an opportunistic feeder. *C. mydas* has been reported to forage on a diversity of macroalgae in the Pacific (Brill *et al.*, 1995), as well as a variety of seagrasses (Bjorndal, 1980; Lanyon *et al.*, 1989; Whiting and Miller 1998). Because *C. mydas* is considered opportunistic regarding their nutritional needs, it is important to track all food items observed.

Tracking preferred macroalgae abundance over time revealed a community that suffered a decline during mid-construction monitoring (Figure 13). However, the community has been slowly recovering through 16-18 month post-construction. The two disturbance events that fall within the mid-construction dates are beach nourishment and the 2005 hurricane season. Because the control sites are positioned outside the project area and were impacted to a similar degree as the experimental sites, it is assumed that the mid-construction shift in abundance is a result of 2005 hurricane season. The differences in recovery rate between control and experimental macroalgae abundances during post-construction monitoring are attributed to the beach nourishment. Control sites were able to recover to pre-construction abundances by 9-12 month post-construction, whereas, experimental sites have not yet returned to pre-construction levels. As shown by the sediment dynamics section of this report, it is evident that migration of nourishment sand to the nearshore hardbottom acts as the mechanism limiting available substrate in which preferred macroalgae by *C. mydas* can recruit. This has resulted in a phase lag of recovery of the preferred macroalgae communities. Full recovery should be expected based on extrapolation of the current data trends.

For the past five years, juvenile green turtle estimates have been recorded within the nearshore waters of Broward County (Makowski *et al.*, 2007; full report Appendix X) which reported a decrease in turtle observations by 29.8% from pre-construction to post-construction in Segment III. Segment II turtle observations decreased by 10.5%.

In conclusion, the macroalgae community composition in the nearshore 30 m of hardbottom has shifted in response to 2005 hurricane season and beach nourishment activities. Beach nourishment has significantly reduced *C. mydas* nutritional resources on nearshore hardbottom. Further data collection will track the macroalgae recovery in the experimental sites and determine if a new state of equilibrium has been established in the macroalgae community or if pre-construction community levels will be re-established.

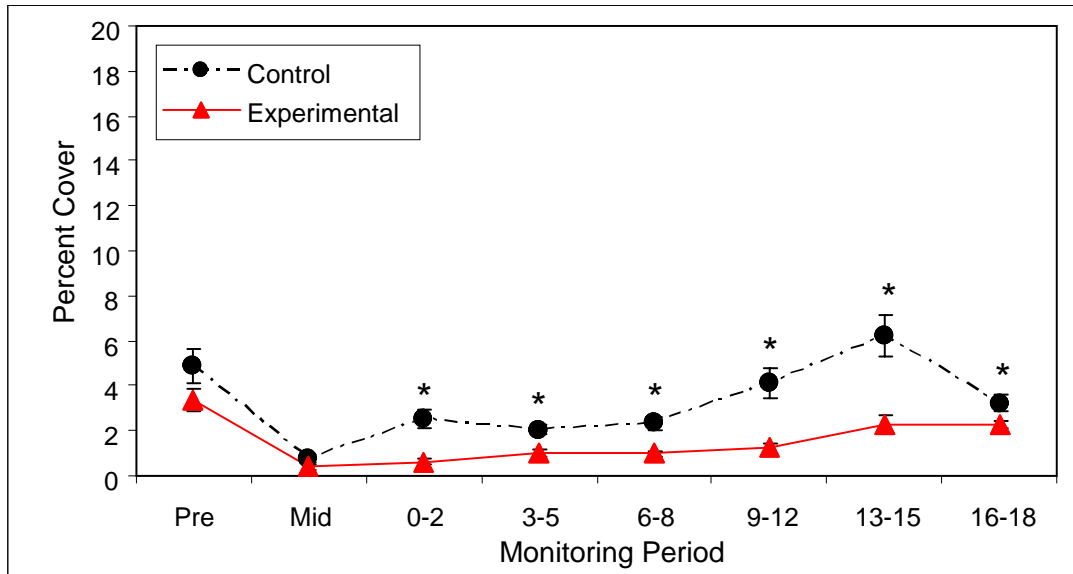


Figure 13. Mean percent cover of *C. mydas* preferred macroalgae at control and experimental sites with standard error bars during grouped monitoring periods. Significant differences ($\alpha = 0.05$) in percent cover are indicated by an asterisk (*).

BEAMR Coral

No differences were found in percent stony coral cover among control and experimental areas over all monitoring periods (Figure 14). Prior to of beach construction the percent cover of corals in experimental transects exhibited declines that appear largely initiated by the unusually strong hurricane season of 2004. Following this event, however, general trends in coral percent cover were stationary through time and statistically indistinguishable between control and experimental areas. Additionally, spatial patterns and general trends in stony coral species composition indicate few impacts from beach construction.

Temporal trends in the occurrence of *Siderastrea* spp. corals reflect that this genus was less likely to occur in re-nourished areas than control areas following the commencement of beach construction suggesting nourishment negatively impacted the *Siderastrea* spp. population in the project area (Figure 15). However, non-metric analyses of species abundance data failed to reflect broader community changes as a result of project effects.

Also, while there do appear to be temporal trends in coral community change, these effects are expressed across all areas, regardless of transect type. Broader changes in coral community characteristics therefore appear to be more related to the 2004-2005 hurricane seasons than to beach construction. Coral cover and community characteristics within the project area of Broward County appear to have been less impacted by project related effects than by natural variability. There appear to be, therefore, no unequivocal project effects in overall stony coral area cover, or coral species community assemblage characteristics.

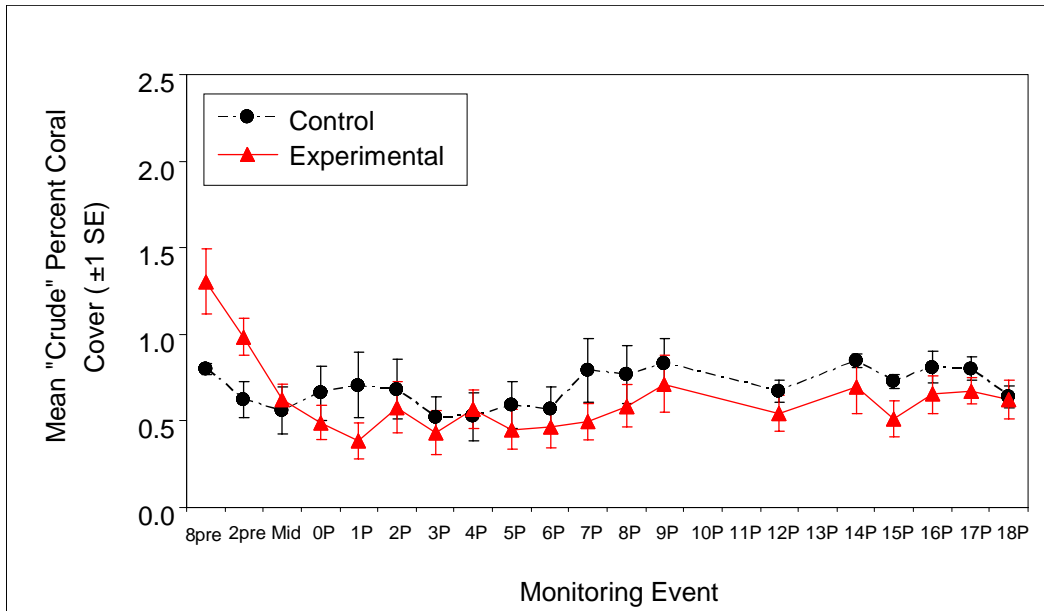


Figure 14. Transect mean percent cover of corals (± 1 S.E.) among treatments and at each monitoring event.

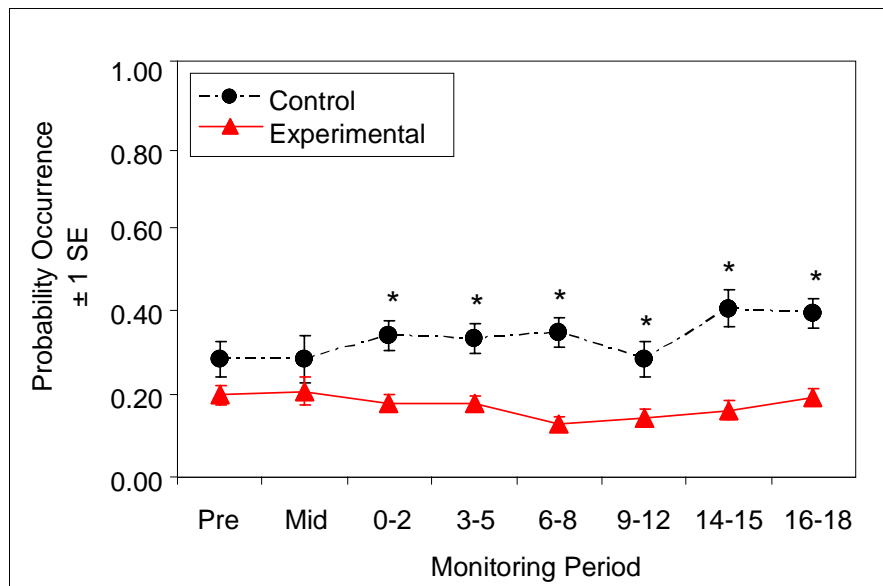


Figure 15. The probability occurrence of large (> 2 cm) colony *Siderastrea* spp. among quadrats at each monitoring event. Significant differences between control and experimental treatments are indicated by an asterisk (*).

4.2 Video for PointCount Analysis

PointCount analyses are robust but give relatively low resolution assessments of a large area. Because percent cover of most functional groups was very low, the analyses were only able to detect meaningful changes in sand, substrate, and macroalgae. These variables had the majority

of overall transect percent cover and were thus the key indicators regarding change in the benthic community. Due to the low resolution of the data generated by PointCount, the pattern described in the analysis should only be used to verify and validate the high resolution assessments generated by BEAMR data (*in situ* assessment).

4.3 Coral Stress

It is well documented that natural and artificial sedimentation constitutes one of the biggest threats to reef organisms, especially coral species (reviewed by Rogers, 1990). Increasing sedimentation leads to lower growth rates, loss of symbiotic algae, and necrosis of underlying tissue (Lasker, 1980; Peters and Pilson, 1985; Rogers, 1990). An adaptive, four-tiered, Stress Index was developed to describe and assess coral health status in the field during the dredging activities of the Broward County Shore Protection Project, Segment III. The index score (0-3) for visually assessing coral is based on the conditions described by Vargas-Angel *et al.* (2004).

Coral stress levels were investigated in short and long-term time scales to determine if beach construction affected stress levels of three scleractinian species (*Montastrea cavernosa*, *Solenastrea bournoni*, and *Siderastrea siderea*). The first 12 coral colonies greater than 5 cm along each 92-m transect were evaluated. The coral stress index used to assess short term analyses focused on stress levels during the 39 weeks of beach construction. Elevated coral stress levels during this period could be a result of increased turbidity and sedimentation due to nourishment and/or hurricanes. Long-term analyses focused on stress levels from mid-construction through 18-month post-construction. Potential coral stressors at this time scale would include sediment accumulation and exclude turbidity.

During mid-construction, control and experimental coral stress levels were measured weekly and fluctuated from 0.5 to 1.5 with an exception in Week 10 when coral stress levels peaked at 2.0 for both control and experimental site types. The only widespread stressor that could have caused this spike in both site types was the passing of Hurricane Dennis near South Florida on 8 and 9 July 2005. Because the stress levels were elevated at both site types, there is no indication that beach construction had adverse impacts to the stress levels of the three coral species monitored during project construction. However, by 15-month post-construction, the stress levels at the control and experimental transects were indistinguishable, suggesting project related stress was temporary.

During post-construction, tracking coral health revealed significantly higher stress levels at the experimental sites. Dividing the dataset into 0-30 m and 31-92 m provided greater resolution into the positive relationship between sedimentation and coral stress (Figure 16). The 0-30 m dataset showed significantly higher stress levels during the 3-5 and 6-8 months post-construction monitoring periods, whereas the 31-92 m dataset showed higher levels to be shifted by one date group, to the 6-8 and 9-12 months post-construction monitoring periods. These results, in conjunction with the sediment depth analysis, suggest that the scleractinian community within the monitored areas was adversely impacted by sediment migration off the beaches onto the nearshore hardbottom environment after the completion of project construction.

Individual species had different stress profiles (Figure 17). *S. siderea* demonstrated the greatest stress response to increased sedimentation with an average score of 1.5 during the 3-5 months post-construction monitoring period. The stress level of *S. bournoni* was gradually decreasing as of the 16-18 months post-construction monitoring period. Colony size and morphology is most likely the reason for differences in stress level profiles. Mean colony size of *S. siderea* and *S. bournoni* were 6.9 and 21.1 cm, respectively. The smaller mean colony size of *S. siderea*, along with a more low lying design, make the species more susceptible to burial by sediment migrating onto the nearshore hardbottom. There were too few qualifying *Montastrea cavernosa* colonies to detect any statistically significant trends.

Coral stress profiles decreased with time on all three species. There are potentially two reasons for this result. First, corals in poor health (2-3 scores) will most likely not recover and survive, and since only coral colonies with live tissue are included in the survey, completely dead colonies will not be counted the following monitoring event; this naturally lowers stress levels. Second, the 2005 Hurricane season significantly impacted many levels of the marine ecosystem, the trajectory of decreasing coral stress could be a reflection of a recovering scleractinian community. Because coral stress monitoring began during beach nourishment and 2005 Hurricane season, a pre-event data set is not available to make that determination. Further data collection will provide greater insight into the topics discussed above.

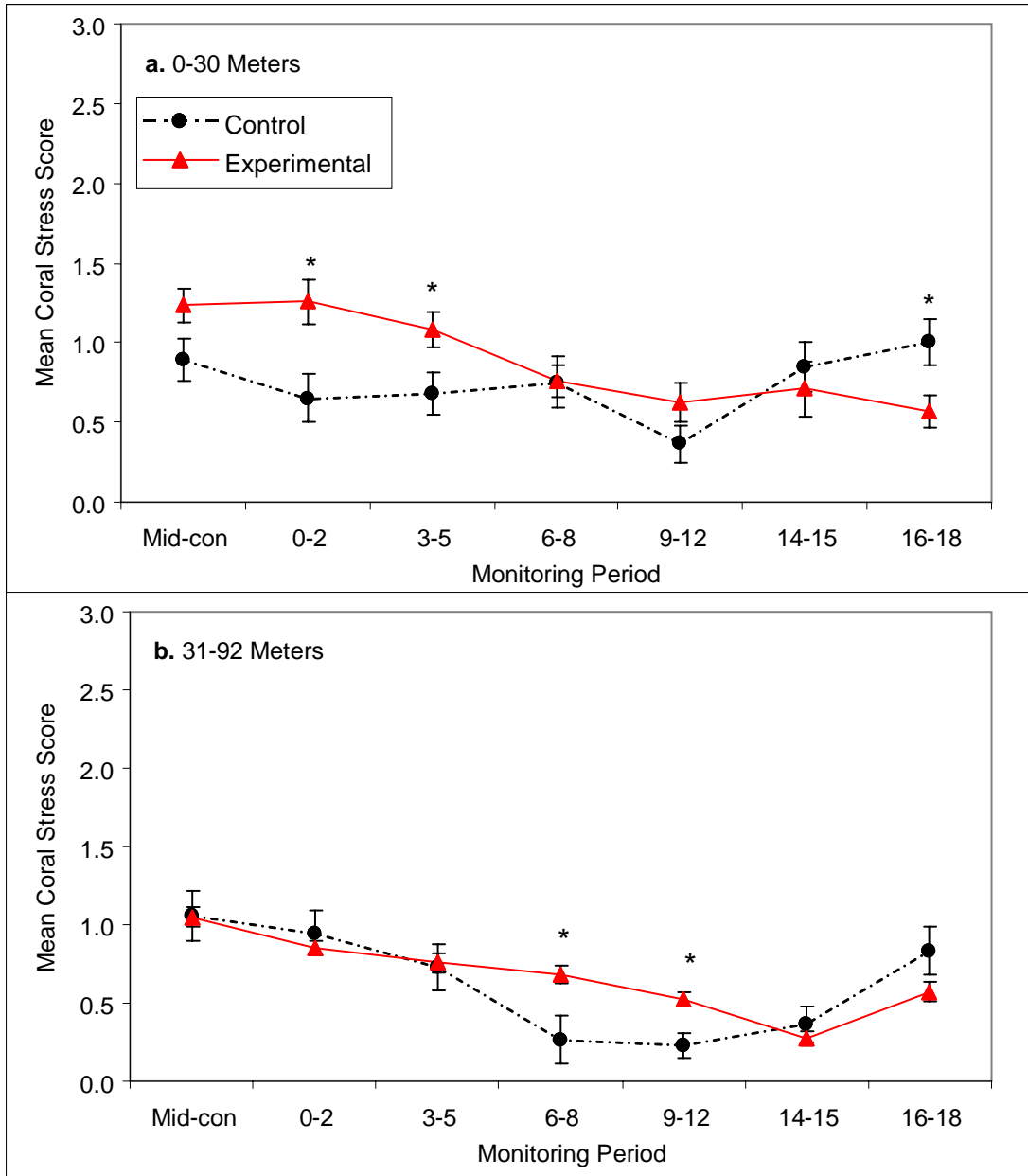


Figure 16. Average coral stress score for control and experimental transects over time for **a.** 0-30 meters and **b.** 31-92 meters. Significant differences ($\alpha = 0.05$) between controls and experimentals are indicated by an asterisk (*).

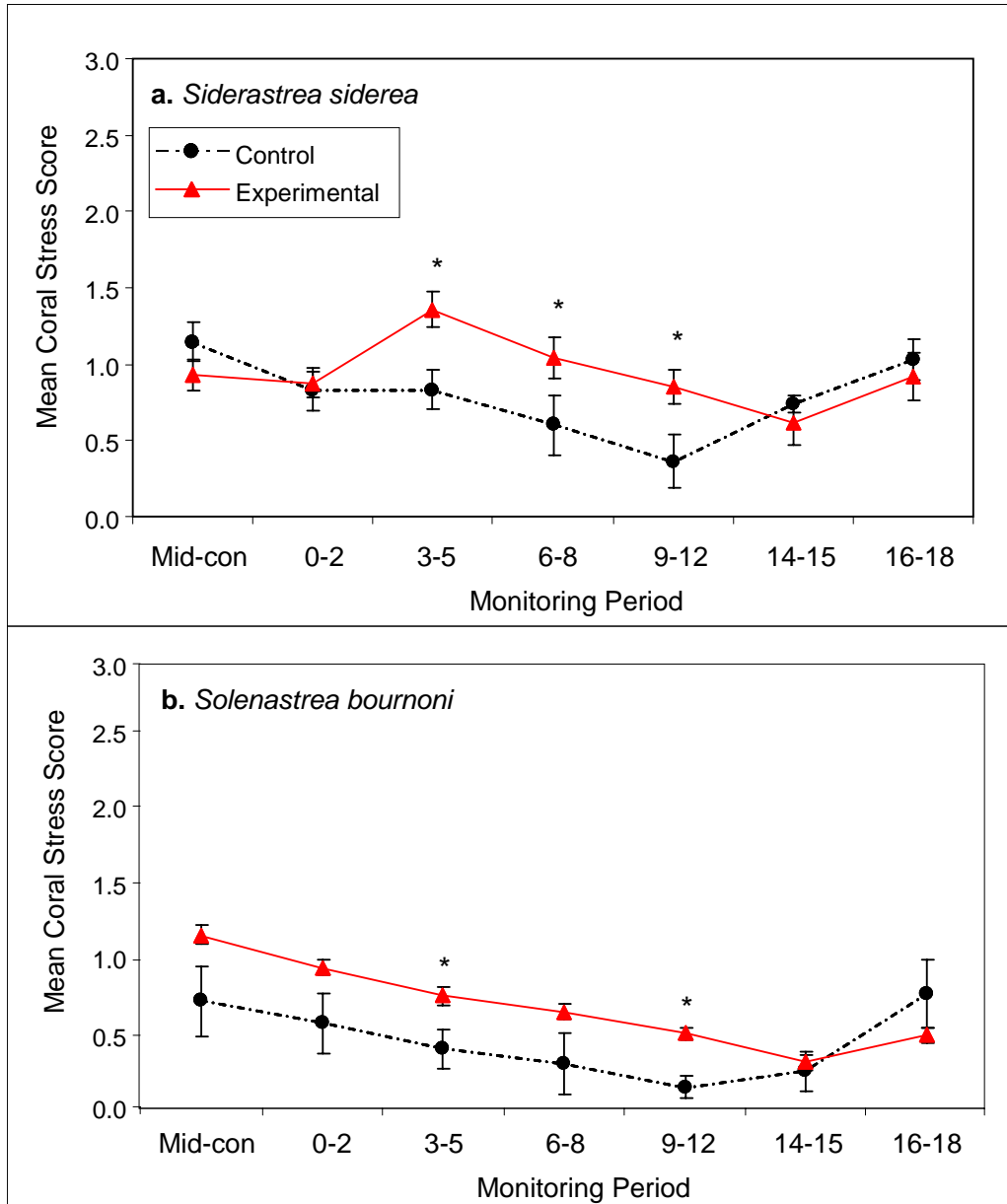


Figure 17. Average coral stress score for control and experimental transects over time for **a.** *Siderastrea siderea* and **b.** *Solenastrea bournoni*. Significant differences ($\alpha = 0.05$) between controls and experimentals are indicated by an asterisk (*).

4.4 Coral Fate-Tracking Stations

The purpose of establishing the coral fate-tracking stations was to quantify changes in stony coral colonies on first-reef habitat disassociated with the nearshore hardbottom edge. The probability of stony coral mortality was found to differ based on coral morphological type (branching or massive); the odds of mortality in branching form corals was 16-times greater than that of massive form corals (Figure 18). Many studies of the effects of hurricanes on corals have demonstrated increased mortality in branching forms over massive forms (Ball *et al.*, 1967;

Glynn *et al.*, 1976; Woodley *et al.*, 1981; Grigg 1995; Bries *et al.*, 2004). These effects are largely contributed to increased susceptibility of branching corals to abrasion and skeletal fracture from wave action and associated moving debris, conditions which occurred during the 2005 hurricane season. Beach construction appears to have had few persistent effects on coral survivorship.

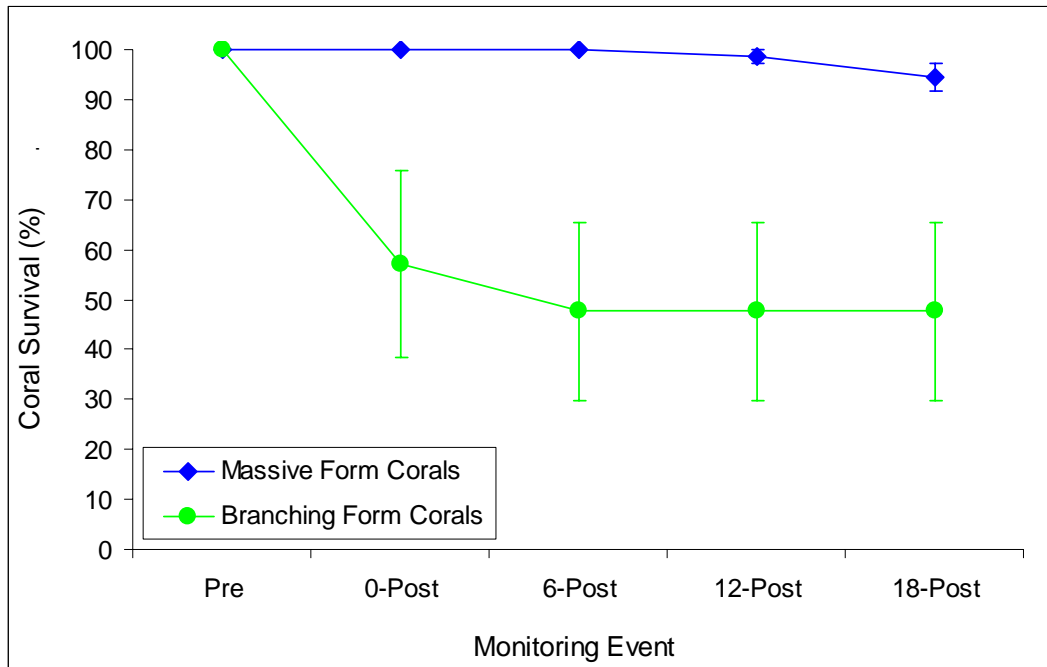


Figure 18. The proportion (± 1 standard error) of massive and branching form stony corals surviving from 2-month pre-construction (Pre) until 0-, 6-, 12-, and 18-month post-construction at the coral fate-tracking stations.

Mean coral stress from the stony coral species *Montastrea cavernosa*, *Siderastrea siderea*, and *Solenastrea bournoni* increased between pre- and 1-month post-construction and 8- and 18-month post-construction (Figure 19); however, regression analysis revealed no significant relationship between mean sediment depth and mean stress levels. Between species, *M. cavernosa* mean stress level was highest pre-construction and decreased over time except for a notable increase at 17-month post-construction; again, regression analysis indicated no relationship between stress level and mean sediment depth. Neither *S. siderea* nor *S. bournoni* mean stress levels exhibited any consistent temporal trends or relationship to mean sediment depth.

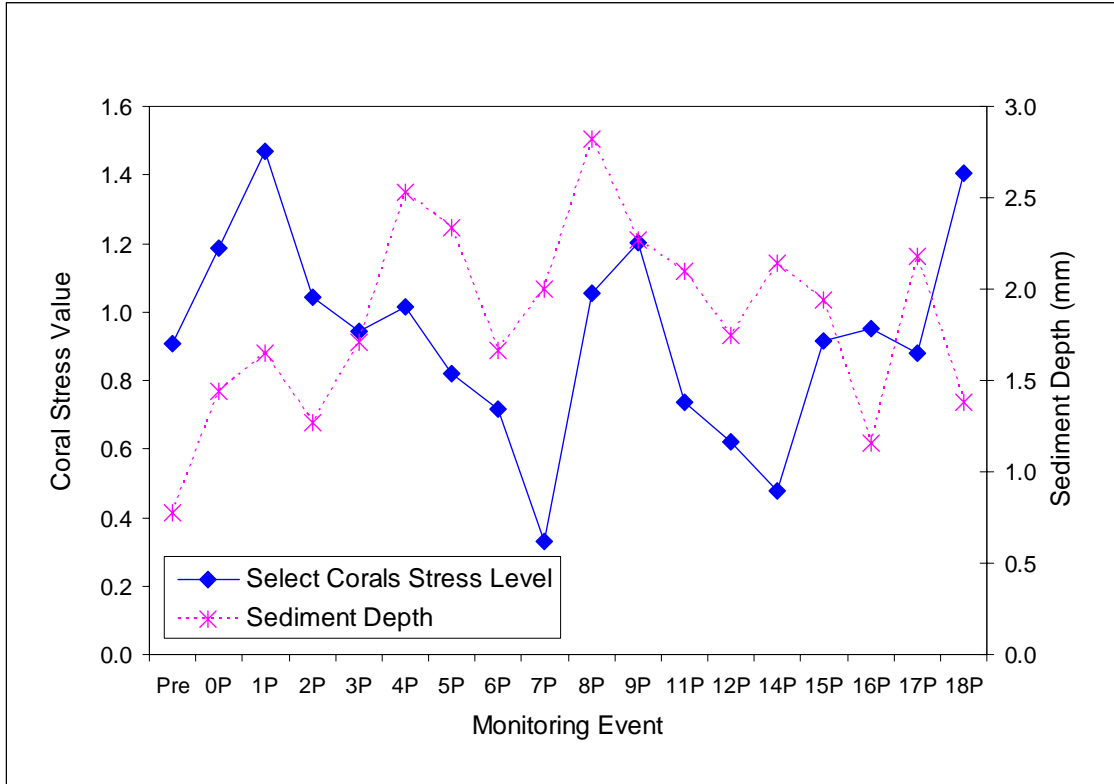


Figure 19. The mean coral stress level of *Montastrea cavernosa*, *Siderastrea siderea*, and *Solenastrea bournoni* colonies and the mean sediment depth from all coral fate-tracking stations.

Of the five *A. cervicornis* colonies monitored in three of the stations, only three colonies survived between pre-construction and 18-month post-construction. Out of these three, only one colony showed any growth (Table 4), and the colony diameter increased at a linear rate of 12.8 cm yr⁻¹, which agrees with rates reported by Shinn (1966) of 7-13 cm yr⁻¹. The remaining two *A. cervicornis* colonies decreased in size over the two year time period.

Table 4. Percent cover of live tissue on *Acropora cervicornis* colonies at the large stations.

Station	Coral #	% Live Tissue				
		2-Pre	0-Post	6-Post	12-Post	18-Post
L120c	8	90%	0%	0%	0%	0%
	9	90%	40%	40%	60%	10%
L120d	7	98%	94%	99%	95%	95%
L121c	3	90%	70%	95%	85%	90%
	5	65%	3%	0%	0%	0%

The coral fate-tracking stations proved to be an informative method of tracking nearshore coral colonies; however, as stated above, no monitoring was performed during beach construction or during the 2005 hurricane season. Because of this, impacts cannot be fully attributed to either event. It is likely that a combination of events caused the initial increase in stress and coral mortality. It is suggested that for future monitoring of coral fate-tracking stations additional pre-

construction and mid-construction monitoring events be considered to increase the robustness of the dataset.

5.0 CONCLUSION

In this report we sought to answer a single broad question:

Were there quantifiable, negative, secondary impacts to the nearshore habitat as a result of construction of Segment III of the Broward County Shore Protection Project?

To answer this question, physical and biological components of the nearshore habitat associated with the Project were monitored prior to construction, during construction, and for 18 months following construction. A nearshore area that was not associated with the Project was designated as a control and was monitored with similar frequency.

Observations and analyses of data collected during 18 months of post-construction monitoring indicate that benthic habitat loss has occurred as a result of beach renourishment activities. Flux in available habitat appears to be driving the survival and success of many benthic organisms based upon their unique life history strategies. Counter intuitively, organisms that are well suited to the sedimentation and scouring common in the nearshore environment exhibited discernable impacts from beach renourishment, while those that are not as well suited exhibited few or indeterminable effects. This may result from the tendency of sand to migrate out of the construction area through low-relief corridors (*e.g.*, Finkl, 2004), not typically occupied by slow growing, or less precocious, organisms. Overall, however, physical habitat availability in the nearshore environment is returning to levels that are comparable to pre-construction. In the absence of latent or further long-term effects, biotic components are expected to recover quickly.

In conclusion, beach renourishment does appear to have negatively impacted the nearshore hardbottom habitat of Segment III of the Broward County Shore Protection Project. The subsequent re-emergence of habitable substrate indicates that negative effects to biota may be temporary. These 18-month post-construction results are preliminary. Beach fill equilibrium is not expected to occur until three years post-construction (FDEP Permit No. 0163435-001-JC). Subsequent post-construction monitoring will provide more data and detail regarding any long-term effects that beach construction may have on the nearshore benthic community.

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