WETLAND MITIGATION EVALUATION REPORT FLORIDA KEYS BRIDGE REPLACEMENT

State of Florida
Department of Transportation
Environmental Management Office
605 Suwannee Street
Tallahassee, Florida 32399-0450

Research performed by:

Roy R. Lewis III, C.E.P.
Curtis R. Kruer
Sally F. Treat
Stephanie M. Morris

FL-ER-55-94

ENVIRONMENTAL RESEARCH

WETLAND MITIGATION EVALUATION REPORT FLORIDA KEYS BRIDGE REPLACEMENT

State of Florida
Department of Transportation
Environmental Management Office
605 Suwannee Street
Tallahassee, Florida 32399-0450

Research performed by:

Roy R. Lewis III, C.E.P.
Curtis R. Kruer
Sally F. Treat
Stephanie M. Morris

FL-ER-55-94

WETLAND MITIGATION EVALUATION REPORT
FLORIDA KEYS BRIDGE REPLACEMENT

WPI No. 6116901; SP No. 90000-1560

Roy R. Lewis III, C.E.P.
Curtis R. Kruer
Sally F. Treat
LEWIS ENVIRONMENTAL SERVICES, INC.
P.O. Box 20005, Tampa, FL 33622
P.O. Box 420334, Summerland Key, FL 33042

Stephanie M. Morris
R. H. MILLER & ASSOCIATES, INC.
1800 N. Douglas Rd.
Pembroke Pines, FL 33024

March 30, 1994

CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE		PAGE

FIGURE		PAGE
37A-B	Lake Surprise, transect 1, 1993	48
38A-B	Lake Surprise, transect 2, 1993	49
39	Lake surprise, transect 3, 1993	50
40-41	Boog Powell spit, 1981 and 1991	53
42	7-Mile Bridge sites of seagrass damage	54
43-44	Sites D and E, 1981 and 1991	56
45-46	Site F	57
47-48	Prop-dredged site (Site B), 1981 and 1991	59
49-50	Niles Channel Site 1, 1983 and 1993	60
51-52	Aerial photography, Bahia Honda, 1981 and 1991	62
53	Construction drawing, Bahia Honda	64
54	Temporal variation of salinity at Bahia Honda	65
55	Benthic fauna at Bahia Honda	66
56-57	Bahia Honda lagoon, circulation cut 4/81 and 7/93	67
58-59	Bahia Honda lagoon, mangrove colonization 4/81 and 7/93	68
60-61	Bahia Honda lagoon, view from U.S. 1, 5/85 and 7/93	69
62-63	Bahia Honda lagoon, roseate spoonbill and person, 1993	70
64-65	Culvert C2 under Boca Chica Road	73
66-67	Culvert C3 under Boca Chica Road	75

EXECUTIVE SUMMARY

From 1912 to 1935, the Florida Keys were connected to the mainland by Henry Flagler's Overseas Railroad. The 1935 Labor Day Hurricane destroyed most of the railroad from Plantation Key to Vaca Key. The track and roadbed stretching 156 miles from Key West to Homestead were purchased by the state of Florida and the Overseas Highway (U.S. 1) was constructed over the railroad right-of-way. Because of structural deterioration in the intervening years, the 1976 Florida Legislature authorized the Keys Bridge Replacement Program at an estimated cost of $175 million. Work commenced in 1977 and was completed in 1983.

Regulatory review of the Florida Department of Transportation's permit applications to replace 37 of the 41 bridges in the Keys raised environmental concerns about the loss of mangroves and seagrasses during bridge construction and the impact of fill causeways on hydrological conditions in upper Florida Bay. Final analysis of the overall impact of the construction projects indicated that 51.03 acres of mangrove were permanently lost and 47.62 acres of seagrass were permanently lost to dredging, filling, or shading. An additional 45.71 acres of seagrass were impacted by propeller cutting or prop wash effects, for a total of 93.33 acres.

Acre-for-acre revegetation and causeway removal to the historical pre-Flagler shoreline would have been logistically and economically prohibitive. Consequently, a 3-phase mitigation plan was designed to address the environmental concerns (Appendix A). This plan included re-opening or enhancing coastal lagoon systems at Boca Chica, Lower Sugarloaf and Bahia Honda, totaling nearly 800 acres of restored wetland habitat. A second component was an experimental seagrass planting at Craig Key in 1979, which led to an FDOT-funded seagrass restoration program in the Keys in 1982 and 1983. The final component was careful initial documentation of the results of these efforts in the mid-1980s, followed by this research effort some ten years after the completion of these projects to provide a "lessons learned" document for concerned parties.

The major findings of this report are:

1. Natural revegetation and recovery from damage in impacted seagrass meadows, **where conditions were appropriate**, far exceeded any success from manual planting of seagrass sprigs.
2. Salvage of seagrass plug units from areas where construction is to occur is a very successful and rapid way to establish seagrass mitigation areas, particularly for slow-growing species such as turtle grass (*Thalassia testudinum*).
3. Restoring tidal connections to stressed tidal lagoons results in very large-scale and cost-effective mangrove **and seagrass** restoration, but culvert connections in some locations may require maintenance on a 10-year cycle.
4. Mangrove planting has an appropriate role in certain locations, but generally does not greatly accelerate establishment of mangroves over that which would naturally occur once shoreline waves are dampened by riprap or tidal connections restored.
5. Natural slope revegetation supplemented by mulching can establish a very stable vegetative community equivalent to a sodded slope, if traffic is kept off the upper slope adjacent to the road. Repeated mulching may be necessary on some exposed slopes.

6. This project determined that the mangrove mitigation efforts produced a minimum of 33.37 acres of new mangroves through natural recolonization and planting, producing 17.66 acres less of actual vegetated mitigation area than that which was impacted. However, approximately 800 acres of previously isolated and stressed mangrove lagoons were restored to normal tidal influence, far exceeding the shortfall by improving the stressed mangrove habitats in these areas.
7. Seagrass mitigation efforts and natural recovery in prop cut areas have resulted in 134.19 acres of successful mitigation, exceeding the original impact by 40.86 acres.

INTRODUCTION

This wetland mitigation evaluation study was undertaken to evaluate five different types of wetland mitigation projects that were constructed as part of the original construction of the Florida Keys Bridge Replacement Program. This program replaced 37 bridges in Monroe County, Florida (Figures 1-3; Table 1) between 1978 and 1983.

As part of the permitting of the bridge construction, requirements for wetland mitigation were placed in the permits by the Florida Department of Environmental Regulation (now the Florida Department of Environmental Protection, FDEP) and the U.S. Army Corps of Engineers (COE) (Appendix A and B). This mitigation can be categorized as one of five types:

I. Mangrove plantings and natural recolonization
   A. Mangrove plantings located at the toe of slopes of some bridge approaches where rubble berms were constructed
   B. Mangrove plantings adjacent to the Boca Chica Naval Air Station
II. Seagrass plantings and natural recolonization
   A. Seagrass planting
   B. Seagrass restoration without planting
III. Prop-dredged site monitoring
IV. Tidal circulation restoration and culvert installations
V. Slope revegetation

I. MANGROVE MITIGATION

A total of 51.03 acres of mangroves were permanently lost to fill or excavation associated with the bridge replacement program (FDOT summary dated September 15, 1982, Appendix A). Mitigation for these impacts was initially negotiated by the Florida Department of Transportation to consist of an equal area of establishment of "appropriate mangrove vegetation" along 42,250 feet of created shoreline edge habitat at the toe of slope of filled causeways. The language in the December 13, 1976 Memorandum of Understanding (MOU) between FDOT and FDER (Appendix B) required that "a dense mat of seagrass litter containing mangrove seed will be strewn" within a swale protected by rubble (Figures 4-5).

One year following mangrove seed distribution, success of the effort was to be jointly determined. If it was determined that "mangrove establishment has not been achieved to a desirable extent", mangrove seedlings were to be planted along the intertidal areas at a "density of at least one (1) seedlings for each five (5) lineal feet of shoreline." This specification is not really a density requirement but a linear spacing requirement that ignores the width of the swale.

A negotiated revision to the requirements of the MOU was made in 1979 (memo from J. C. Kraft to J. W. Brown dated May 26, 1979) that substituted re-establishment of tidal circulation to artificially impounded mangrove areas to total 700-800 acres (see section III) for a portion of the required mangrove seeding/planting. The reason for the change is referenced in the memo as the eventual realization that "suitable habitat in public ownership was not available for replacement vegetation (approximately 60 acres)."

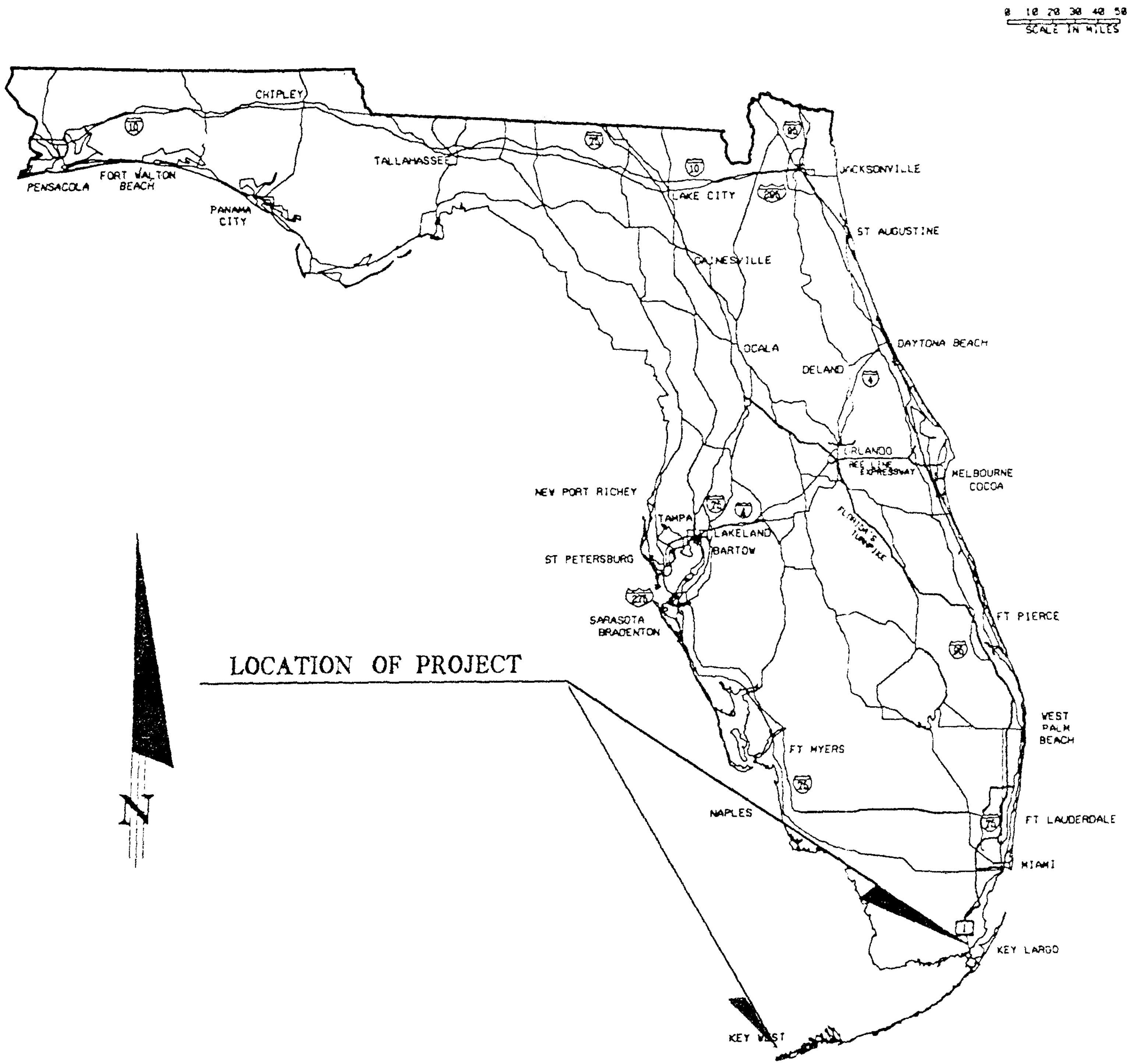
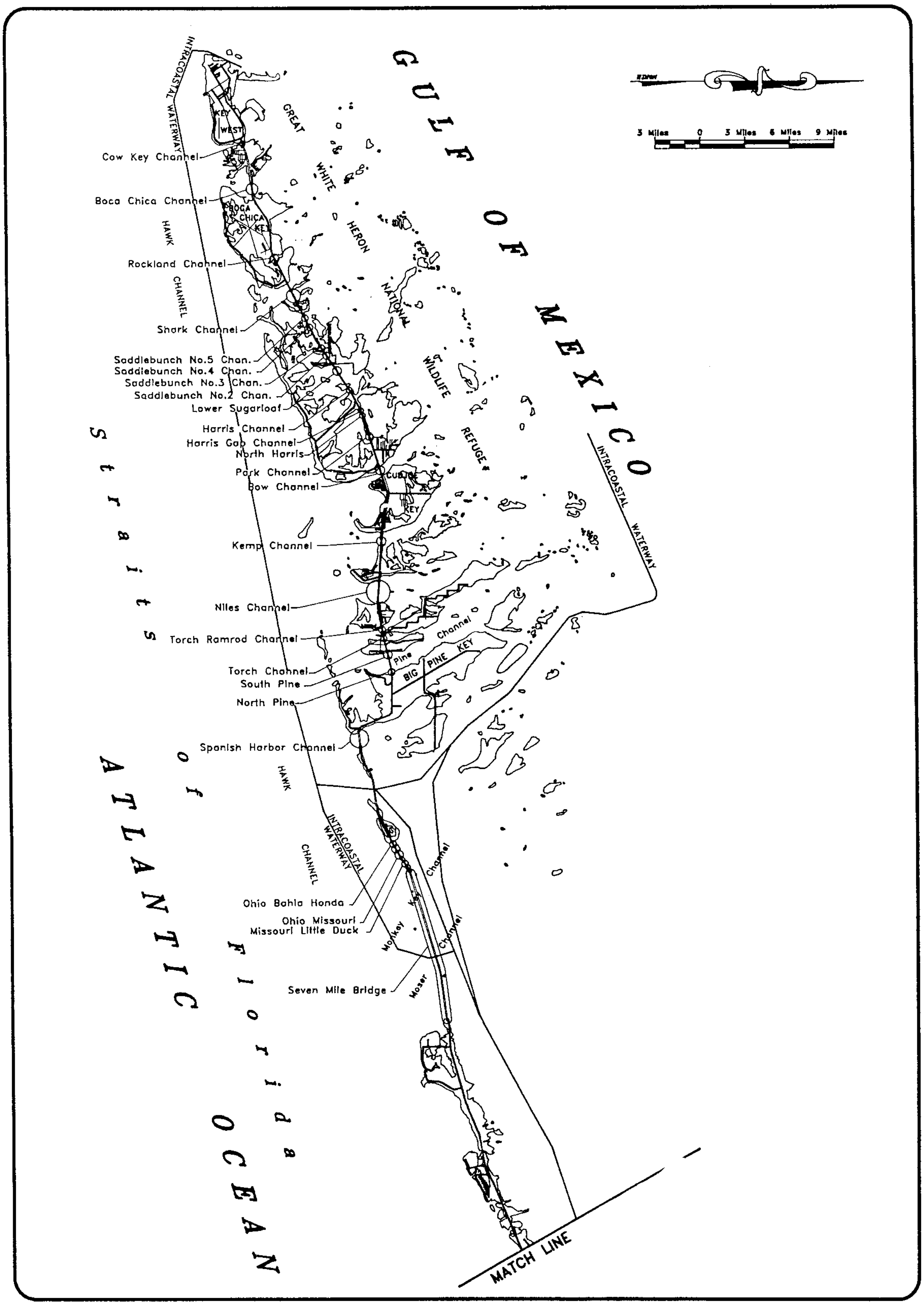
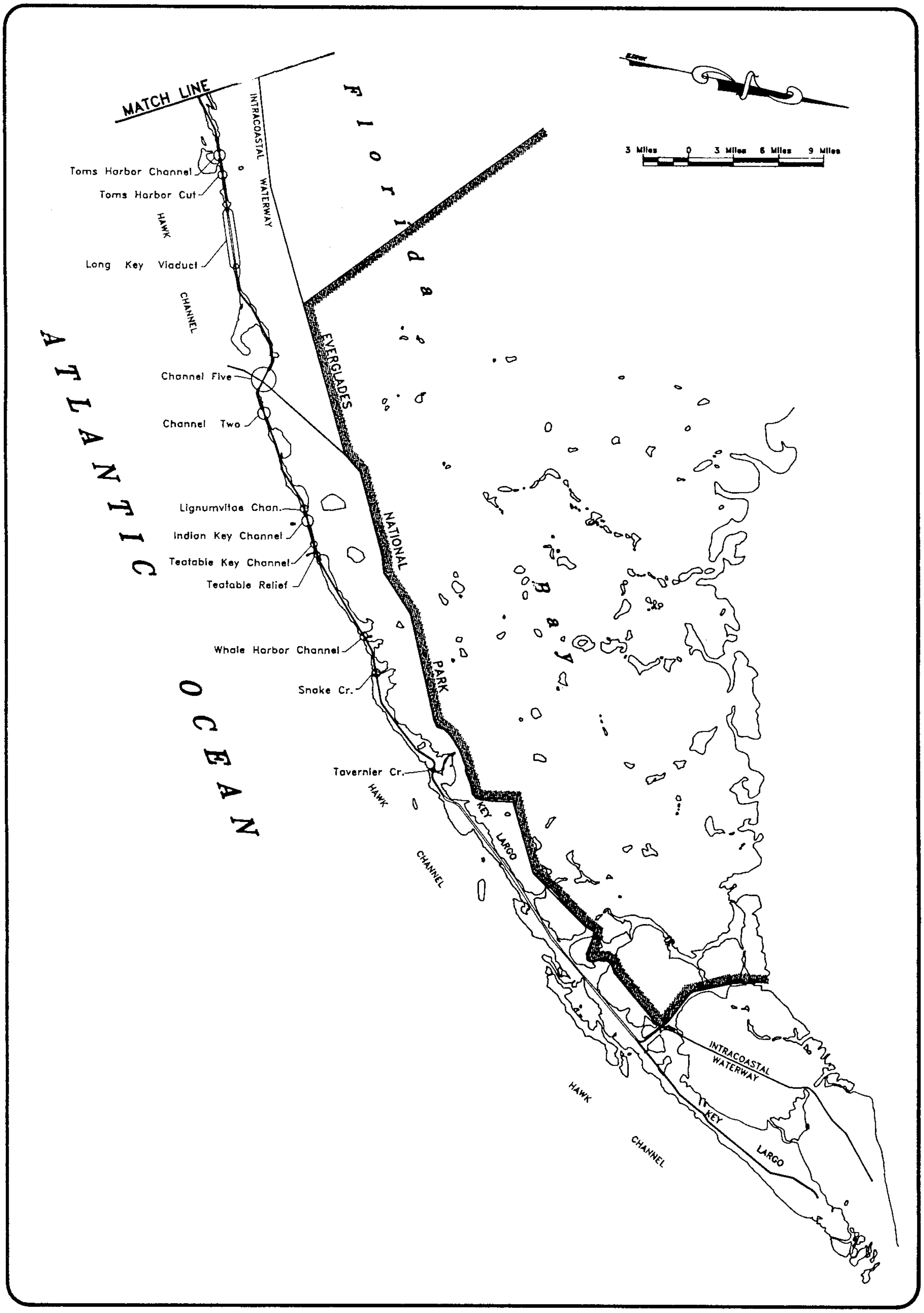


Figure 1. Project location.



LEWIS ENVIRONMENTAL SERVICES. INC.
TAMPA , FT. LAUDERDALE & SUMMERLAND KEY, FL.
(813) 889-9684

Figure 2. Lower Keys bridge locations.



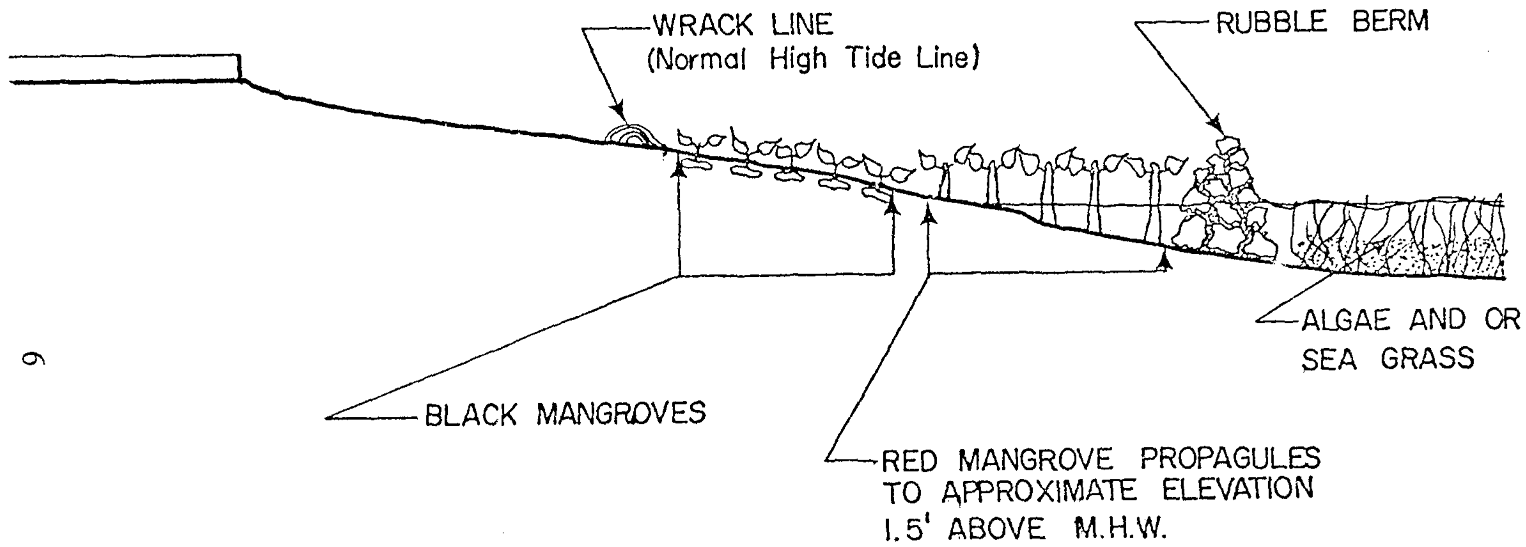
LEWIS ENVIRONMENTAL SERVICES, INC.
TAMPA, FT. LAUDERDALE & SUMMERLAND KEY, FL.
(813) 889-9684

Figure 3. Upper Keys bridge locations.

Table 1. Listing of the 37 bridges that were part of the Florida Keys Bridge Replacement Program.

	LENGTH (FT)	COMPLETION DATE
Tavernier Creek	320	12/78
Snake Creek	230	7/81
Whale Harbor	720	12/78
Tea Table Relief	270	6/80
Tea Table Channel	700	6/80
Indian Key	2,460	7/81
Lignum Vitae	860	7/81
Channel No. 2	1,760	11/80
Channel No. 5	4,580	10/82
Long Key	12,040	7/81
Tom's Harbor Cut	1,270	5/80
Tom's Harbor	1,460	5/80
Seven Mile	35,830	10/82
Missouri Little Duck	840	6/81
Ohio Missouri	1,440	6/81
Ohio Bahia Honda	1,050	6/81
Spanish Harbor	3,380	80-81
North Pine	660	80-81
South Pine	850	80-81
Torch Channel	880	80-81
Torch Ramrod	720	80-81
Niles Channel	4,490	80-81
Kemp Channel	1,030	80-81
Bow Channel	1,340	80-81
Park Channel	880	80-81
North Harris Channel	430	80-81
Harris Gap Channel	140	80-81
Harris Channel	430	80-81
Lower Sugarloaf Channel	1,260	4/80
Saddlebunch No. 2	660	4/80
Saddlebunch No. 3	760	4/80
Saddlebunch No. 4	900	6/80
Saddlebunch No. 5	900	6/80
Shark Channel	2,090	1/80
Rockland Channel	1,280	7/79
Boca Chica Channel	2,730	11/80
Cow Key Channel	360	3/78

BOCACHICA CAUSEWAY GULF SIDE
SPANISH HARBOR KEY WEST SIDE BAHIA HONDA BRIDGE (borrow pit site)
COMMUNITY COLLEGE ROAD BOTH SIDES
BARNES SOUND EAST SIDE



NOTE: 1. No Rubble Berm Will Be Required At Community College Road or At The Western End of The West Bocachica Causeway, or The Western Side of The Borrow Pit On Spanish Harbor Key.

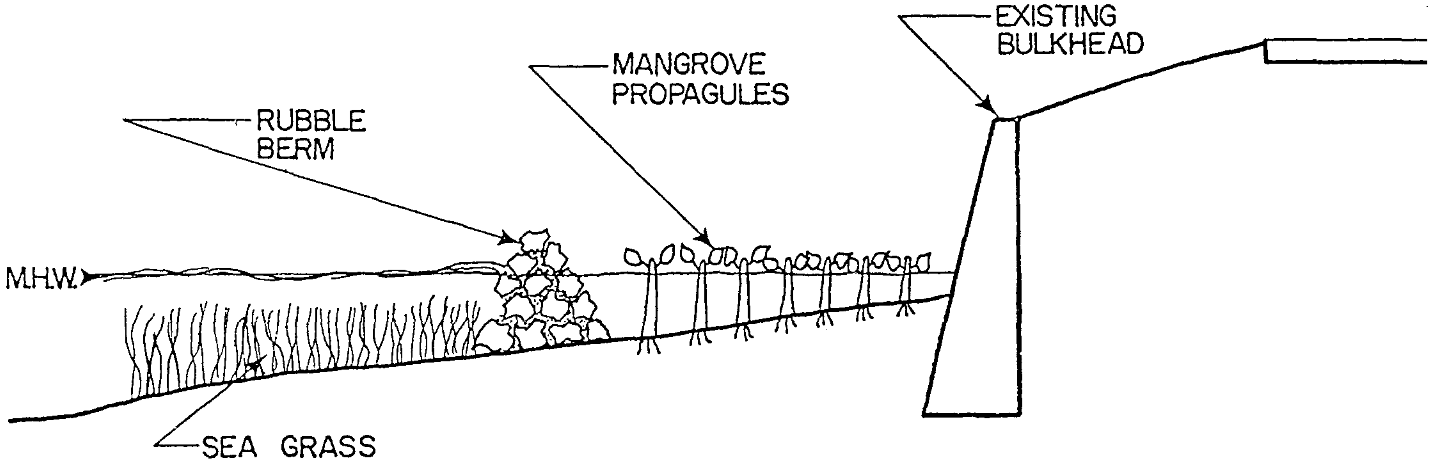
2. Seaward Limits of The Planting Area Will Be Controlled by The Incidence of Algae and/or Seagrass Stands and/or The Practical Limits of Water Depths for Planting The Propagules, but In No Case Will Extend Beyond The - 2.0' Contour Line.

Drawing of the proposed toe of slope treatment provided as an attachment to a letter dated July 1, 1977, from J. C. Kraft, Florida Department of Transportation, to Colonel Donald A. Wisdom, District Engineer, Corps of Engineers, Jacksonville.

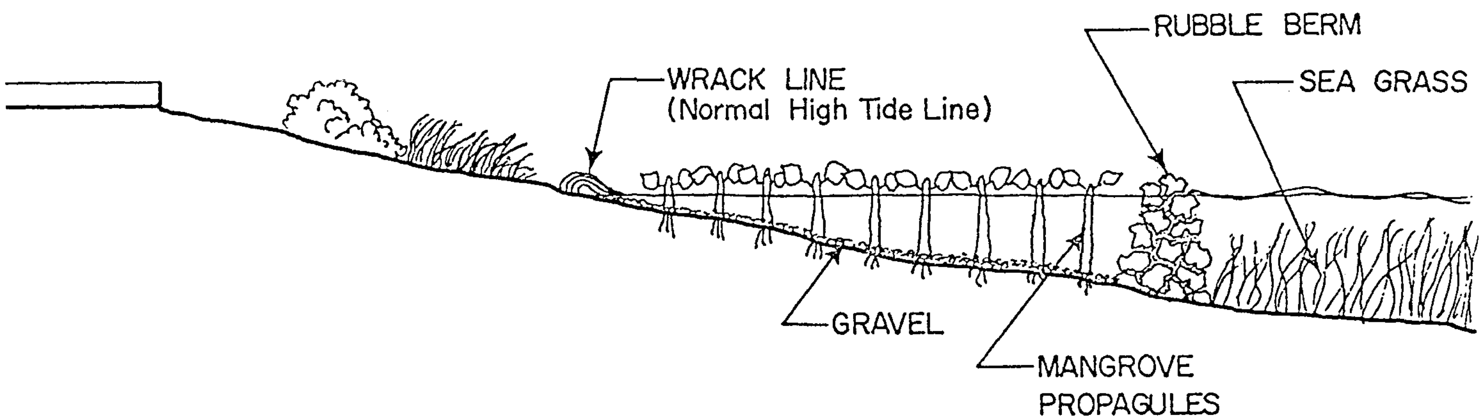
Figure 4 Proposed toe of slope treatment.

Figure 5.

SPANISH HARBOR KEY GULF SIDE



SPANISH HARBOR KEY ATLANTIC SIDE



NOTE: 1. Seaward Limits of The Planting Area Will Be Controlled by The Incidence of Algae and/or Seagrass Stands and/or The Practical Limits of Water Depths for Planting The Propagules, but In No Case Will Extend Beyond The - 2.0' Contour Line.

Drawings of the proposed toe of slope treatment provided as an attachment to the same letter referenced in Figure 4

Table 2. Data obtained from representative 2-m wide transects at the toe-of-slope of mangrove reforestation areas.

APPROXIMATE LOCATION	TRANSECT #	WETLANDS	LENGTH (m)	PERCENT COVER	AVG. HEIGHT (m)	EXPOSURE	RIPRAP WIDTH (m)	OUTSIDE DEPTH (m)
Junior College Rd planted	1, 2, 3	Mangrove	7.3	100		low	none	0.1
		red		30	4.0			
		black		13	4.5			
		white		57	4.0			
		Transitional	2.0	69				
		buttonwood		60	3.5			
		sea purslane		2				
		smartgrass		2				
		sea ox-eye		5				
Boca Chica Channel Key West Gulf 700 m west of bridge, planted	1	Mangrove	3.3	89		low	none	0.2
		red		85	3.0			
		black		2	2.0			
		white		2	2.0			
		Transitional	4.0	88				
		sea daisy		30				
		sea purslane		40				
		paspalum		10				
		gentian		1				
		bay cedar		2				
		buttonwood		5	1.0			
Key West Gulf 850 m west of bridge, planted	2	Mangrove	8.3	35		low	none	0.0
		red		25	1.5			
		black		5	0.8			
		white		5	1.5			
		Transitional	4.0	42				
		sea purslane		15				
		smutgrass		1				
		coastal dropseed		20				
		bay cedar		2				
		yellowtop		2				
		red mangrove seedlings		2				

(continued)

Table 2 continued.

APPROXIMATE LOCATION	TRANSECT #	WETLANDS	LENGTH (m)	PERCENT COVER	AVG. HEIGHT (m)	EXPOSURE	RIPRAP WIDTH (m)	OUTSIDE DEPTH (m)
Boca Chica Channel Key West Gulf	3	Mangrove	4.3	94		moderate	none	
500 m west of bridge, planted		red		90	2.5			
		black		2	1.0			
		white		2	0.5			
		Transitional	8.3	94				
		sea purslane		10				
		black mangrove		2				
		bay cedar		15				
		coastal dropseed		10				
		ambrosia		2				
		buttonwood		35	2.0			
		smartgrass		10				
		unid. grass		10				
300 m west of bridge, planted	4	Mangrove	4.3	40		high	0.5 (low)	0.5
		red		15	2.0			
		black		25	1.0			
		Transitional	4.0	28				
		sea daisy		5				
		bay cedar		20				
		sedges		2				
		yellowtop		1				
150 m west of bridge, planted	5	Mangrove	5.5	0				
		Transitional	6.2	62		high	0.5 (low)	0.5
		sea daisy		10				
		sea purslane		5				
		buttonwood		20	1.5			
		sea ox-eye		10				
		beach carpet		2				
		foxtail		2				
		broom sedge		2				
		spurge		1				
		unid. grass		1				

(continued)

Table 2 continued.

APPROXIMATE LOCATION	TRANSECT #	WETLANDS	LENGTH (m)	PERCENT COVER	AVG. HEIGHT (m)	EXPOSURE	RIPRAP WIDTH (m)	OUTISDE DEPTH (m)
Boca Chica Channel Miami Gulf planted	6	Mangrove	8.9	65		high	2.0 (high)	0.5
		red		25	1.3			
		black		25	1.3			
		white		5	1.0			
		turtle grass		5				
		shoal grass		5				
		Transitional	4.9	47				
		sea daisy		15				
		bay cedar		15	1.0			
		buttonwood		5	1.0			
		sea grape		5	0.5			
		broom sedge		5				
		unid. grass		5				
Miami Gulf planted	7	Mangrove	2.9	95		moderate	1.5	0.2
		red		45	2.0			
		black		45	1.0			
		turtle grass		5				
		Transitional	4.0	26				
		sea ox-eye		10				
		sea purslane		5				
		sedges		2				
		grasswort		2				
		white mangrove		2				
		unid. grass		5				
Miami Gulf planted	8	Mangrove	7.4	31		low	1.5 (low)	0.1
		red		10	1.0			
		black		1	0.3			
		white		5	1.0			
		turtle grass		15				
		Transitional	6.1	38				
		annual glasswort		5				
		sea daisy		2				
		buttonwood		10	1.0			
		sea purslane		1				
		unid. grass		15				
		broom sedge		5				

(continued)

Table 2 continued.

APPROXIMATE LOCATION	TRANSECT #	WETLANDS	LENGTH (m)	PERCENT COVER	AVG. HEIGHT (m)	EXPOSURE	RIPRAP WIDTH (m)	OUTSIDE DEPTH (m)
Shark Channel Key West Gulf 200 m west of Shark Key	1	Mangrove	5.0	35		high	1.0 (low)	0.5
		red		25	1.0			
		black		10	0.3			
		Transitional	4.0	20				
		buttonwood		15	1.5			
		unid. grass		5				
Miami Gulf 75 m east of bridge	2	Mangrove	5.4	45		low	4.5	0.0
		red		40	1.0			
		white		5	1.0			
		Transitional	3.1	15				
		buttonwood		10	0.3			
		unid. grass		5				
Saddlebunch #5 Miami Gulf 75 m east of bridge	1	Mangrove	5.0	65		low	4.0 (low)	0.0
		red		50	1.5			
		white		5	0.3			
		glasswort		10				
		Transitional	2.4	25				
		buttonwood		15	0.5			
		unid. grass		10				
Saddlebunch #4 Key West Gulf 40 m west of bridge	1	Mangrove	6.8	20		moderate	3.0	0.1
		red		10	0.8			
		white		5	0.2			
		glasswort		5				
		Transitional	2.2	10				
		buttonwood		10	0.3			
Saddlebunch #2 Miami Gulf 75 m east of bridge	1	Mangrove	5.0	45		low	2.5	0.0
		red		40	1.5			
		black		5	0.3			
		Transitional	3.0	60				
		buttonwood		60	0.5			

(continued)

Table 2 continued.

APPROXIMATE LOCATION	TRANSECT #	WETLANDS	LENGTH (m)	PERCENT COVER	AVG. HEIGHT (m)	EXPOSURE	RIPRAP WIDTH (m)	OUTSIDE DEPTH (m)
Lower Sugarloaf Channel	1	Mangrove	6.0	100		moderate	4.0	0.1
Key West Gulf 350 m west of bridge		red		100	3.5			
		Transitional	2.6	75				
		buttonwood		20	2.0			
		sea grape		15	0.5			
		broom sedge		20				
		unid. grass		20				
Key West Gulf 100 m west of bridge	2	Mangrove	7.0	30		moderate	4.5 (high)	0.5
		red		30	1.0			
		Transitional	2.0	80				
		buttonwood		70	0.8			
		unid. grass		10				
Miami Gulf 100 m east of bridge	3	Mangrove	6.5	10		high	4.5 (low)	0.5
		red		10	1.0			
		Transitional	3.0	51				
		buttonwood		40	0.5			
		unid. grass		10				
		spurge		1				
Miami Gulf 1500 m east of bridge	4	Mangrove	4.0	15		high	2.0 (low)	0.5
		red		15	1.3			
		Transitional	3.0	31				
		buttonwood		15	0.5			
		sea daisy		15				
		spurge		1				
Spanish Harbor Channel	1	Mangrove	10.0	100		moderate	1.6 (low)	0.0
Miami Atlantic 400 m east of bridge, planted		red		60	7.0			
		black		30	7.0			
		white		10	6.0			

(continued)

Table 2 concluded.

APPROXIMATE LOCATION	TRANSECT #	WETLANDS	LENGTH (m)	PERCENT COVER	AVG. HEIGHT (m)	EXPSOURE	RIPRAP WIDTH (m)	OUTSIDE DEPTH (m)
(Spanish Harbor Channel	1	Transitional	5.0	90				
Miami Atlantic		sea ox-eye		20				
400 m east of		railroad vine		15				
bridge, planted)		sea purslane		10				
		black mangrove		25				
		beggar's tick		10				
		unid. grass		10				
Miami Atlantic	2	Mangrove	9.0	100		moderate	1.6	0.0
450 m east of								
bridge, planted		red		75	6.0			
		black		25	3.0			
		Transitional	7.0	100				
		saltwort		40				
		sea ox-eye		10				
		beggar's tick		10				
		sedges		5				
		railroad vine		5				
		unid. grass		20				
		unid. shrub		10				
Spanish Harbor Ch.	3	Mangrove	5.0	5		high	1.0	0.75
Miami Gulf								
450 m east of		red		5	3.0			
bridge, planted								
		Transitional	5.0	70				
		buttonwood		10	2.0			
		saltwort		60				
Bahia Honda Ch.	1	Mangrove	6.0	100		low-mod.	none	0.0
Key West Gulf								
access road to pit		red		40	5.0			
		black		30	4.0			
		white		30	4.0			
		Transitional		75				
		buttonwood		50	5.0			
		borrichia		10				
		saltwort		15				

Actual mangrove seed planting and monitoring for success apparently took place at four linear locations totaling 16,600 feet. Little detail is available in agency files on these plantings. These sites were:

Bahia Honda	1,400′
Spanish Harbor	2,550′
Boca Chica Bridge Causeway	4,650′
Community College Road (Stock Island)	8,000′
TOTAL	16,600′

To meet a requirement of the 1976 Mitigation MOU, red mangrove seeds were installed at an undetermined number of bridge slopes in the late 1970s by DOT. These were placed along the toe of the slope at a density of one seed per five linear feet of shoreline. It is not known if any mulching with seagrass wrack or other organic matter was done. Reports by DOT staff a few years later indicate that seed survival varied greatly from site to site, and natural recruitment of seeds was occurring.

In addition, 80,000 red mangrove seeds (propagules) were planted adjacent to culvert No. 4 (the most westerly of three FDOT-installed culverts) at the Boca Chica Lagoon.

Four primary areas of mangrove mitigation were investigated during this study to determine the effectiveness of these efforts. These were: A) toe of slope revegetation, planted and natural; B) red mangrove propagule planting at culvert No. 4; C) installation of three culverts to the Boca Chica Lagoon; and D) excavation of a flushing channel into the Bahia Honda Lagoon. Items C and D are discussed in Section IV of this report.

Toe of Slope Revegetation, Planted and Natural

Percent cover of wetland vegetation at various representative locations was measured by laying a 2-meter wide transect from the upper limits of wetlands on the slope to the lower limit of emergent wetland vegetation or the outside of the rock berm, whichever was farthest out. Species of mangroves and transitional wetland plants encountered were listed, percent cover estimated, representative heights measured, and other pertinent information collected (Table 2). This quantitative assessment was performed at most Lower Keys toe of slope sites; inspections and qualitative assessment were made at most other Lower Keys, as well as Middle and Upper Keys sites. Factors influencing the recovering plant community were assessed at all sites visited. An assumption was made that the presence of a FDOT sign noting a planting experiment at the toe of some slopes indicated that planting had occurred.

Figures 6-17 are paired photographs of bridge slopes at Shark Channel, Saddlebunch, and Lower Sugarloaf Channel. The earlier photographs were taken in 1981-82, and the later ones in 1993. These figures also illustrate bridge slope revegetation efforts discussed in Section V of this report.

A number of different factors were determined to have affected the recovering toe of slope plant community. Planted and unplanted sites alike now range from heavily forested, mixed mangrove fringes to slowly recovering, sparse mangroves to barren, eroded, unstable rock rubble. With a few exceptions, these slope wetlands, after about 12

Figure 6. Shark Channel, Miami Gulf side, view east, 2/81.

Figure 7. Shark Channel, natural toe of slope mangrove revegetation, Miami Gulf side, view east, 5/93.

Figure 8. Saddlebunch #5, Miami Gulf side, view east, 2/81.

Figure 9. Saddlebunch #5, Miami Gulf side, view east, 5/93.

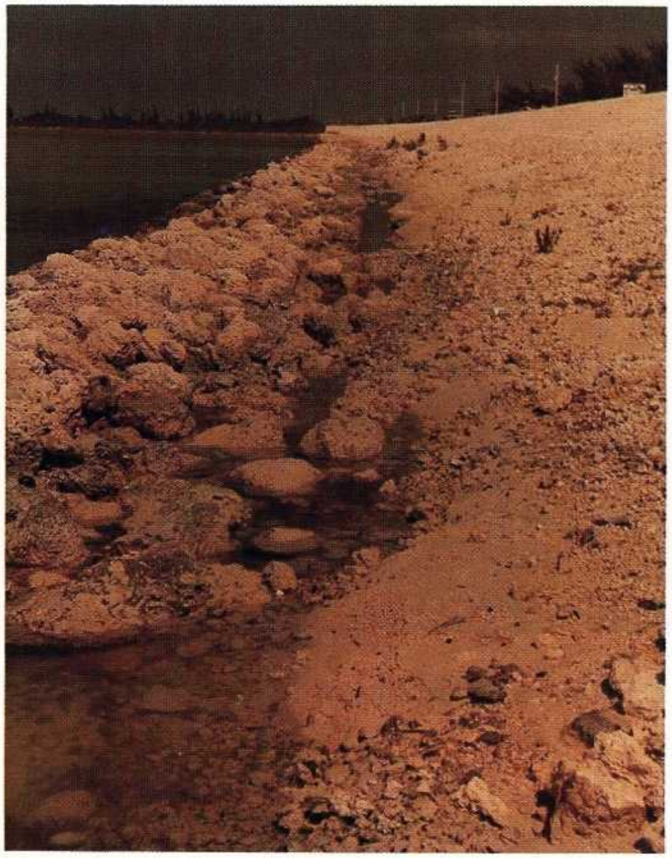


Figure 10. Saddlebunch #2, Miami Gulf side, view east, 2/81.

Figure 11. Saddlebunch #2, natural toe of slope mangrove revegetation, Miami Gulf side, view east, 6/93.

Figure 12. Lower Sugarloaf Channel, Key West Gulf side, view west, 2/81.

Figure 13. Lower Sugarloaf Channel, natural toe of slope mangrove revegetation, Key West Gulf side, 5/93.

Figure 14. Lower Sugarloaf Channel, Key West Gulf side, test plantings (mulch) on slope, view east, 4/82.

Figure 15. Lower Sugarloaf Channel, grassed slope, Miami Gulf side, view east, 11/92.

Figure 16. Lower Sugarloaf Channel, Miami Gulf side, view west, 4/82.

Figure 17. Lower Sugarloaf Channel, erosion limiting revegetation, Miami Gulf side, view west, 5/93.

to 16 years of recovery, now have mixed mangrove fringes from 1 to 2 m in height, of varying width and density. Generally, factors influencing recovery appeared to be:

- exposure
- extent of the riprap berm (height and location on slope)
- slope
- depth offshore
- organic nutrient supply
- seed source
- level of public use

Exposure to wave and current energy appeared to be the factor most influencing mangrove revegetation of the toe of slopes, both planted and unplanted. This is consistent with the findings of Goforth (1984) from his experimental plantings of red mangrove seeds and plants on marl shorelines in the Keys. He reported that on partially protected shorelines, either seeds or plants could be used successfully but exposed shorelines must be planted with at least 2- to 3-year old trees to withstand forces of erosion. Of 21 sites in Table 2 for which "exposure" (low, moderate, high) was identified, those labeled low exposure showed 59% cover by mangroves; those labeled moderate showed 77% cover, and those labeled high showed 24% cover. All toe of slope treatments from Boca Chica to Big Pine were on the north (Gulf) side of U.S. Highway 1. Winter cold fronts with strong northwest to northeast winds have resulted in erosion of lower parts of slopes at Boca Chica Channel (Key West end), Shark Channel (Key West end), Saddlebunch No. 5 (Miami end), Saddlebunch No. 4 (Key West end), Lower Sugarloaf Channel (each end), and Spanish Harbor (Miami, Gulf). At most, the developing mangrove fringe may eventually protect the eroded scarps, allowing transitional vegetation to stabilize the area further.

Some settlement of riprap barriers since placement has occurred, especially in exposed settings or where placed on soft marl substrates. These changes made determination of effectiveness of various riprap heights difficult. Current conditions include a wide range of riprap types, from eroded, redistributed boulders (e.g. Boca Chica/Key West end, Spanish Harbor/Miami Gulf end) to solid, wide riprap at Saddlebunch No. 4 (Key West end) and Saddlebunch No. 3 (Miami end) that may limit mangrove recolonization. Exposed sites (or parts of sites) with little riprap were prone to failure. It appeared that height was an important factor especially as related to exposure and slope behind the riprap (width of mangrove zone). Where rock boulders were placed to the elevation of extreme high tides or above it seemed that better conditions for regrowth occur, but if riprap is too high the overwash of seeds and organic matter cannot occur. Where riprap was too easily overwashed, erosion and unstable conditions resulted, especially where slopes were steep.

The location of riprap line on the slope was also important. Placement, however, often depended on depths offshore and room in which to place the rock. In several locations once the required slope was created for the new roadbed rock had to be placed on offshore seagrasses in order to create a swale. Excessively wide riprap berms resulted in displacement of seagrass beds at several locations. If rock was placed too high on a steep slope with deep water offshore, a narrow, shallow swale resulted behind the rock that appeared slow to revegetate. Ideally, a broad intertidal zone existed where rock could be placed at or just below the mean low water line and an intertidal swale created for mangrove recovery. In some locations though, a wide berm filled much of the intertidal zone; if the berm was low it became vegetated with mangroves, if it was too high and solid it remained unvegetated. It appeared that generally the best condition was a narrow band of stable, large rock boulders placed just below the mean low water line that provided protection vertically to or above the extreme high tide elevation. Some overwash and good flushing to the intertidal or shallow subtidal zone landward of the riprap appeared to be a benefit.

Another type of toe of slope treatment not specifically addressed here is the solid rock rubble treatment given to steep, exposed shorelines adjacent to deep water such as at Kemp Channel (Key West end), the Pine Channel causeway, Tom's Harbor Gulfside shoreline, and Channel Five. Here rock boulders were laid like a blanket over the embankment slope to well into deep water. Valuable intertidal habitat for fish and invertebrates has resulted attracting regular snorkelers and lobster seekers. These slopes have been especially slow to revegetate due to lack of suitable attachment sites and organic material but with time it appears these shorelines will have mixed mangroves fringes, mostly at slightly higher elevations. The Pine Channel causeway is revegetating in the center, away from the wave and current energy of the channels on each end.

Gentle slopes seemed more conducive to regrowth than steep slopes by allowing wave energy to be expended, less erosion of rubble soils, finer sediment to be deposited, and organic material and seeds to be more evenly distributed. Successful planting sites were among the more gently sloping shorelines observed (College Road, Spanish Harbor, Bahia Honda, and the far west end of Boca Chica). By comparing early 1980s photos to 1985 FDOT photos to current conditions it is evident that many moderately steep shorelines were slow to revegetate but now show substantial mangrove fringes (e.g. Park Channel, Harris Gap Channel, and Kemp Channel). Erosion of slopes limiting revegetation was also exacerbated by deep water immediately offshore. Shorelines with shallow water (intertidal) offshore were more protected than those with deep water where wave and current energy were greater, especially around bridge abutments.

Low to moderately protected, low nutrient sites with limited seed sources (e.g. Saddlebunch Channels) appeared slower to revegetate than sites with nearby seed sources and high nutrients. Average height of red mangroves was 1.2 m in the Saddlebunch Channel and Lower Sugarloaf Channel (Miami end) areas. In a shoreline discontinuity that accumulated organic material west of Lower Sugarloaf Channel red mangroves averaged 3.5 m tall. An increase in the height of this fringe heading into the discontinuity can be easily observed. In planted areas subject to accumulation of organic debris accumulation at College Road, Spanish Harbor, and Bahia Honda, red mangroves averaged 5.5 m tall. In planted areas at Boca Chica Channel (east and west) where the straight, more exposed shoreline limits organic buildup, red mangroves averaged 1.9 m tall. Accumulation of organic wrack and seeds behind the riprap was also a function of riprap height. Organic nutrient sources were typically floating seagrasses, algae, and detritus that accumulated in discontinuities. Goforth (1984) reported that nutrients needed to support growth of mangroves appeared to be lacking on most barren marl shorelines in the Keys.

High public use was a factor limiting revegetation of shoreline at the west end of Boca Chica Bridge. Here the combination of foot and vehicular traffic, exposure, limited, unstable riprap, and erosion has resulted in a barren, unstable shoreline. Indian Key Fill and Whale Harbor Channel shorelines also show the result of public use on recovery of vegetation.

In general, where conditions allowed a mangrove fringe to develop a healthy transitional wetland zone developed on the toe of slopes landward of the mangroves. Where conditions prevented a fringe from developing, the transitional zone vegetation is also typically limited. A variety of typical Keys wetland plants were found on these slopes, including the state-listed bay cedar, *Suriana maritima* (Table 2). Invasive exotics such as Australian pine (*Casuarina* spp.), Brazilian pepper (*Schinus terebinthifolius*), and Asiatic colubrina (latherleaf, *Colubrina asiatica*) all appear on the slopes visited. At Spanish Harbor (Miami Atlantic), Asiatic colubrina is overrunning wetlands near a FDOT experiment sign where Australian pine and Brazilian pepper are also well established. In the Upper Keys near Channel No. 5 and other sites Brazilian pepper has established large stands on rock rubble and fill slopes.

Planted Sites

The original planting area at Boca Chica Lagoon, Culvert C-4, (Figure 18) was located and quantitative measurements taken to allow estimation of percent survival, current percent cover, percent cover by volunteers, and determination of growth rates of planted and volunteer mangroves. Aerial photocomparisons (1981 and 1993) are shown in Figures 19 and 20. Ground level photography is shown in Figures 21 and 22.

Most planted sites such as College Road, part of Boca Chica, part of Spanish Harbor, and Bahia Honda Channel, showed extensive mangrove cover (Table 2). But some planted sites, such as part of Boca Chica (Key West end, near bridge) and part of Spanish Harbor (Miami Gulf), showed little cover due to high energy conditions, breaking down of the riprap, and public use. Comparison of representative mangrove heights (regardless of density) measured at study sites showed that mangroves averaged 3.0 m tall at planted sites and 1.1 m tall at unplanted sites (Table 2). Noted, however, is that the sites chosen for planting, especially College Road, Spanish Harbor and Bahia Honda, seemed ideal for planting with low exposure or adjacent shallow water, gentle slopes, organic accumulation, and large seed sources. But portions of the Spanish Harbor area also appeared affected by exposure and appeared to be revegetation failures.

Although numerous mangrove propagules were planted at these sites by FDOT, due to the varying conditions and little monitoring information available, it is impossible to tell if these planting sites are now forested with tall trees as a result of their being planted or due to suitable conditions for natural mangrove recolonization. A 1982 Corps of Engineers memorandum following an inspection of the College Road plantings reported that only about 30% of the mangroves planted had survived (Kruer 1982). So at this site

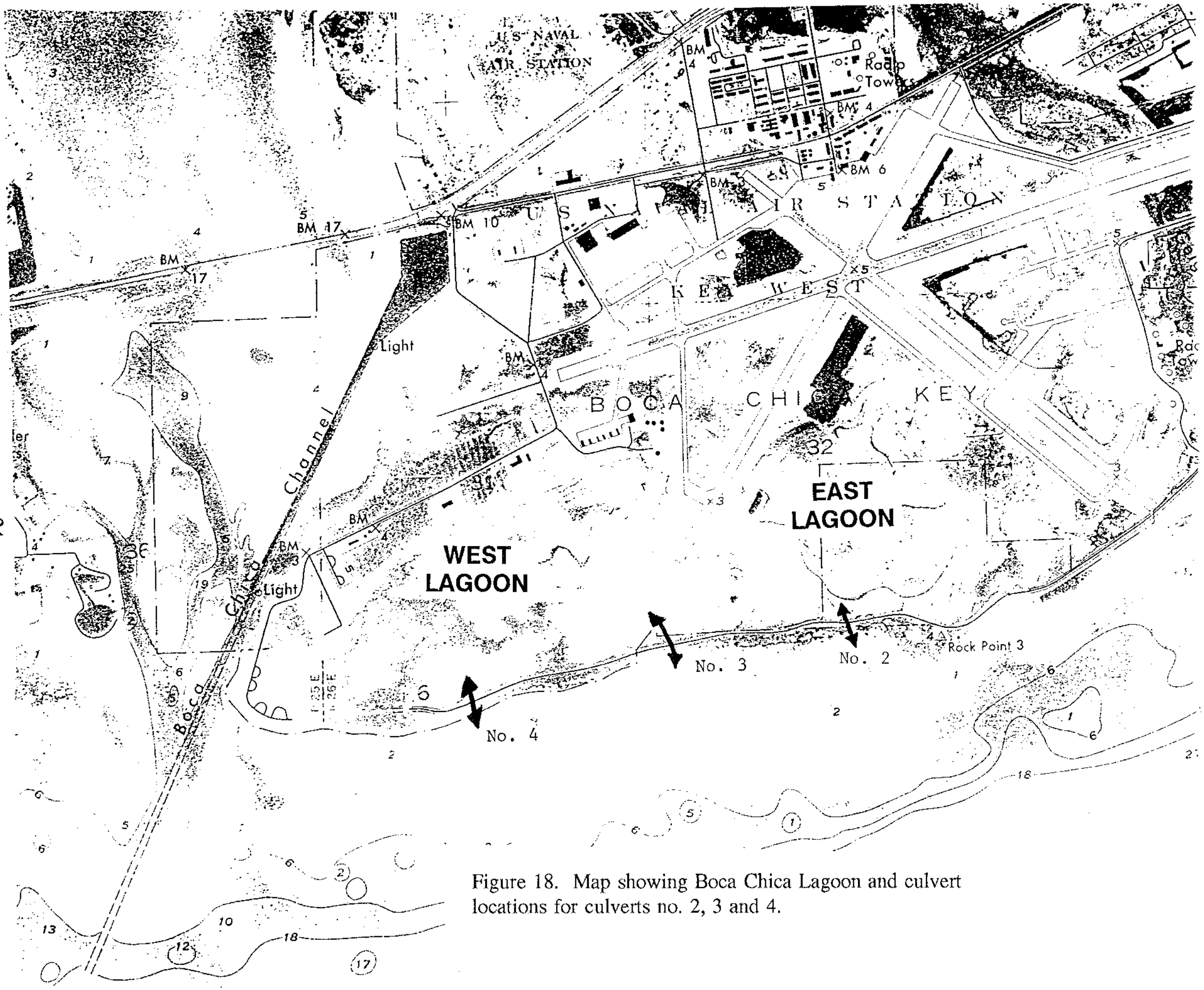


Figure 18. Map showing Boca Chica Lagoon and culvert locations for culverts no. 2, 3 and 4.

Figures 19-20.

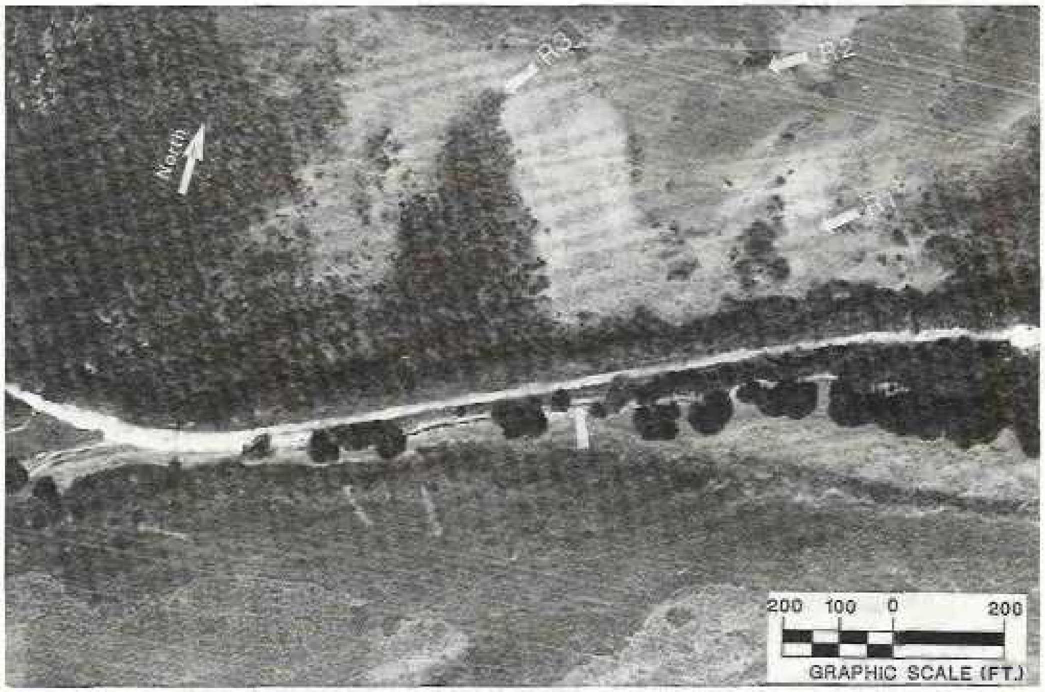


Figure 19. Vertical aerial photograph taken February 25, 1981, of the south side of the Boca Chica Lagoon at the location of culvert C4. Reference points R1, R2 and R3 are also shown below. Arrow indicates future location of culvert (see below).

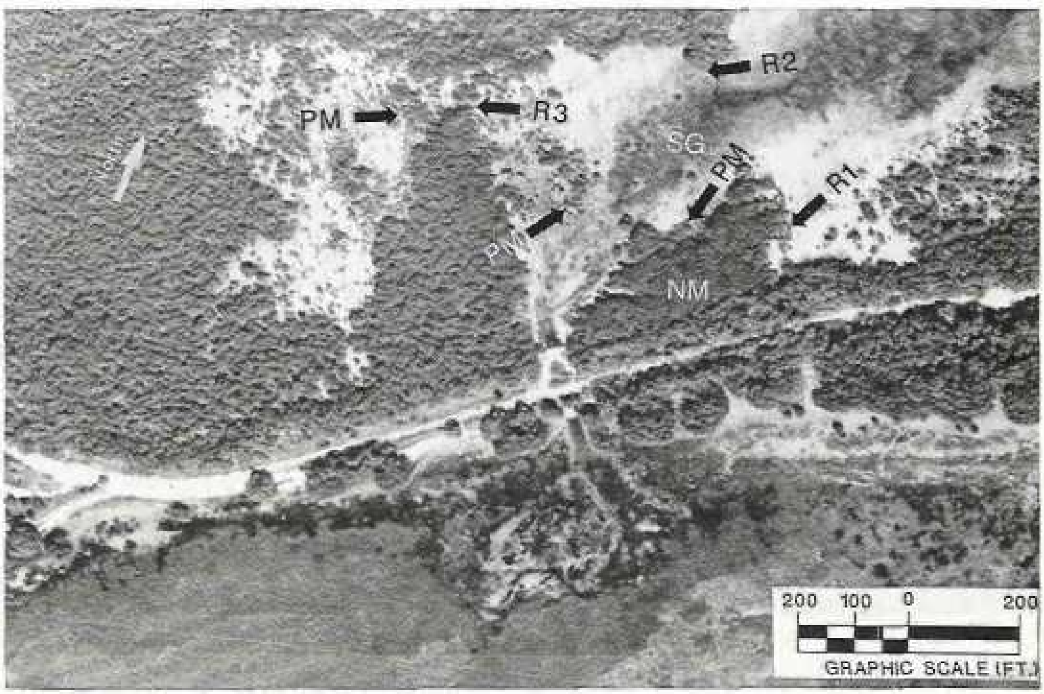


Figure 20. Vertical aerial photograph of the same site, taken February 17, 1991. Reference points are the same as above. R1 indicates a square planted mangrove plot. NM indicates new volunteer mangroves mixed with additional planted mangroves (PM) and SG new volunteer seagrass.

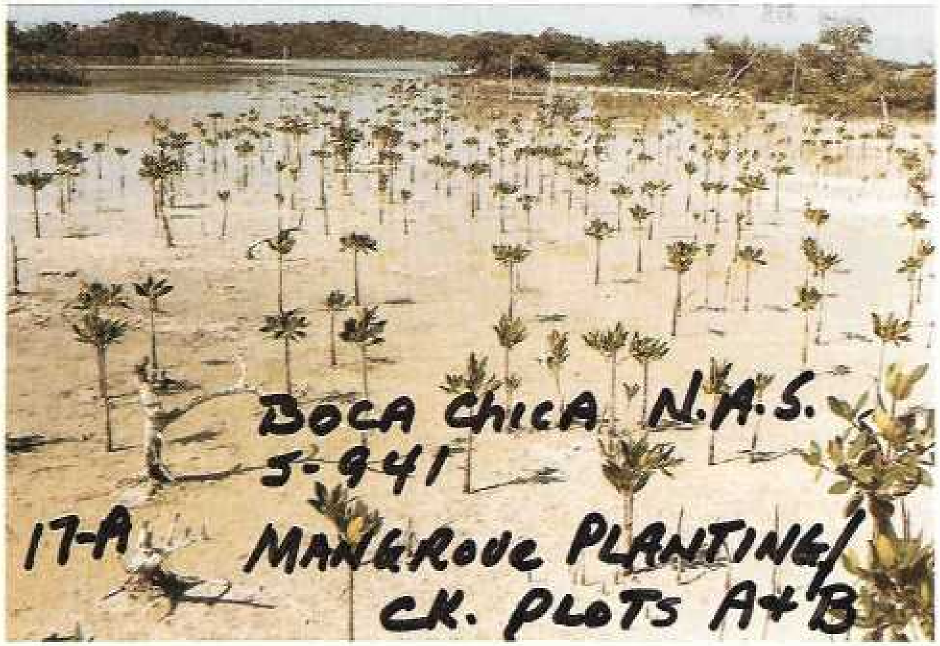


Figure 21. Typical planted red mangroves at culvert C-4, Boca Chica Lagoon, 1985.

Figure 22. Typical volunteer and planted red mangroves at culvert C-4, Boca Chica Lagoon, 1993. Staff is 2 m tall.

natural recruitment may have resulted in the same shoreline now seen. It is likely though that recovery at planted areas occurred more rapidly than at sites not planted.

Based on observations of past restoration projects in the Keys both natural and artificial substrates are usually slow to revegetate after disturbance. Plantings with a good survival rate typically provide an important start to the revegetation process, especially when coupled with organic nutrients. Evidence presented here indicates, however, that many physical forces are controlling influences on the wetland plant community that eventually developed at the toe of these slopes. A total of 33.37 acres of new mangroves were documented to be present as a result of all of the mangrove mitigation efforts (Table 3).

Any future plantings of this type should be designed for the site-specific conditions rather than one generic planting plan to cover a wide variety of conditions. The design of riprap, for example, needs to take into account the fetch and resulting wave energy. More sturdy and higher riprap would be important as fetch and expected wave energy increase. More complete monitoring, particularly in the first few years after completion of the project, would provide a more complete database from which to draw conclusions.

Recommendations

For future efforts to design successful toe of slope revegetation treatments where new crushed limerock fill encroaches into open, shallow, tidal waters, the following steps are recommended:

1. Assess each site (or parts of a site that are different) in terms of exposure, design slope, offshore depth, organic nutrient supply, seed source, and anticipated level of public use.
2. Design riprap barrier size and placement to projected an intertidal zone where recovery of a mangrove fringe is desired (Figure 23). If possible, encroachment into offshore seagrasses should be minimized while still allowing establishment of a stable intertidal zone capable of sustaining a mangrove fringe. The width of this intertidal zone is a function of the design slope which usually reflects the degree of encroachment permitted into roadside wetlands or open waters. A gently sloping, protected intertidal zone about 2-3 meters wide is recommended.
3. Riprap boulders should be large enough to be stable (a function of the degree of exposure). A solid barrier precluding any overwash is not desired as it will preclude organic matter and seeds from being washed into the intertidal zone. An excessively wide barrier is not desired as it may needlessly fill submerged vegetation and is more expensive to construct (see Crewz and Lewis 1991, p. 10 and 46).
4. The decision to plant or not to plant should be based on the degree of exposure (even with riprap), available seed source for natural revegetation, and naturally occurring organic nutrients available to the planting zone. Where seed sources and nutrients can be identified as limited, dense planting with mangrove seedlings and mulching can accelerate the recovery process.
5. Where exposure, depth, or slope create problems for likelihood of successful creation of a mangrove fringe, the solid rock slope approach should be used to create more stable conditions, protecting the slope as well as the offshore benthic habitats. As seen in the Keys, mangroves will eventually establish a foothold in

this rock, and the submerged rock slope provides important subtidal habitat for fish and invertebrates.

Table 3. Acreage of new mangroves.

Toe of slope (bridges)		14.5*
Bahia Honda		1.35
Boca Chica Culverts:	C-2	6.45
	C-3	4.58
	C-4	6.49
TOTAL		33.37 acres

*based on average width of mangrove zones at 19 sites (Table 2)

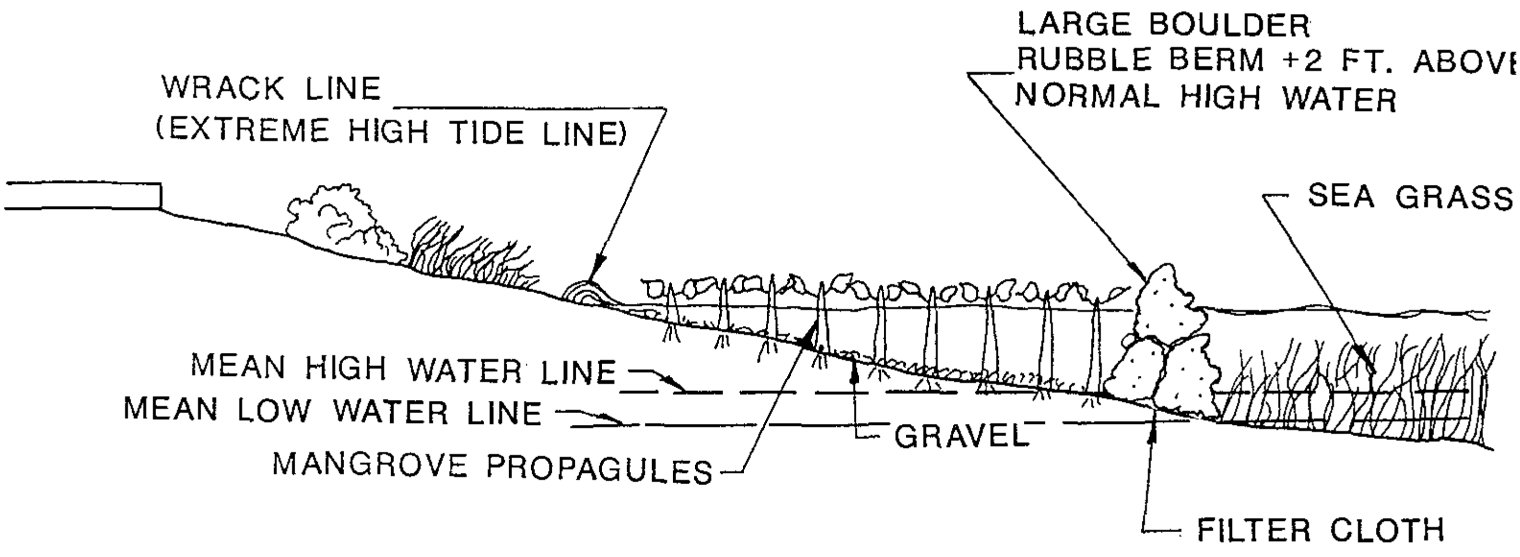


Figure 23. Idealized version of Figure 4 illustrating the best location of toe of slope features and the need to ensure that the rubble berm is large and high enough to redue wave action during windstorms and periods of high water.

II. SEAGRASS MITIGATION

The areal extent of seagrass meadows destroyed as a direct result of bridge construction was originally estimated at 65.80 acres (Mangrove Systems, Inc. 1985). This has been revised to include additional prop cut damage, bringing the total to 93.33 acres (Table 4). Of the 93.33 acres total, 30.52 acres were considered not restorable, due to permanent loss through filling, bridge shading, and post-disturbance substrate (i.e., rock bottoms with no available sediment structure).

The remaining 62.81 acres, distributed over 22 sites, were determined to be capable of supporting restoration efforts or having potential for natural recovery. Additionally, 17.00 acres of restorable seagrass damage not related to bridge construction became available concurrent with restoration efforts, providing a potential for 79.81 acres of restoration, not including any recolonization in the re-opened lagoons (see Section IV).

The choice of methods of restoration was based on a Department of Transportation funded study conducted at Craig Key (Figure 24) between 1979 and 1981 (Continental Shelf Associates, Inc. 1982), a one-year follow-up study in 1982 (Lewis 1987), and a separate planting effort in Lake Surprise (Figure 25) conducted in 1982 (Derrenbacker and Lewis 1983). These two projects are described first since they were inspected as part of this project.

Craig Key

The Craig Key site is located on the southeast side of Craig Key and consists of a 3.4-acre borrow pit that had silted in with fine calcareous sand and silt since its creation during dredging activities approximately 35 years earlier (Figure 26). Water depths averaged 1.2-1.5 m at mean low water and the area was surrounded with a shallow (0.3-0.6 m MLW) sill, probably corresponding to the original undisturbed bottom. This adjacent area was well-vegetated with *Thalassia testudinum*. A large portion of the site was vegetated with green algae or colonizing seagrasses (*Thalassia*, *Halodule*, *Thalassia-Halodule* mixture). Approximately 25% of the site was largely barren of vegetation (Lewis and Phillips 1981).

Plugs, sprigs (turions) and seedlings were used. Plugs and sprigs of *T. testudinum*, *H. wrightii*, and *S. filiforme* were planted 13-16 February 1979. *Thalassia* seedlings were planted at the site on 16 August 1979 (Figure 27).

Plugs consisted of intact sediments and plant material approximately 22 cm x 22 cm x 10 cm high (Figure 28). Sprigs consisted of individual plants with rhizomes and roots cleaned of existing sediment, and were attached to small concrete anchors with plastic ties before planting. Seedlings were abundant and collected in the intertidal zone at Craig and Lower Matecumbe Keys. Small plastic ties were investigated for use as seedling anchors, but were not used because of anticipated detrimental effects to the delicate blades of the seedlings.

Each plot contained seven rows by seven rows of plant material for a total of 49 loci planted in each plot. One plug or sprig was planted at each locus; five seedlings were planted at each, for a total of 245 seedlings per plot.

Table 4. Seagrass acreage lost, Keys bridges (modified from MSI 1985).

BRIDGE	FILLED	DREDGED	PROPELLER WASH/CUTS	SHADED	TOTAL
Rockland	—	—	0.14	—	0.14
Shark	0.48	2.11	—	—	2.59
Saddlebunch #5	—	—	0.17	0.42	0.59
Saddlebunch #4	0.05	—	1.73	0.82	2.60
Saddlebunch #3	0.61	—	0.41	0.70	1.72
Saddlebunch #2	1.13	—	—	—	1.13
L. Sugarloaf	1.91	—	—	1,19	3.01
Harris Channel	1.08	—	—	0.23	1.31
Harris Gap	0.45	—	—	—	0.45
N. Harris	0.38	—	—	—	0.38
Park Channel	1.45	—	—	0.52	1.97
Bow Channel	0.73	—	—	0.93	1.66
Kemp Channel	1.55	—	—	0.12	1.67
Niles Channel	2.49	—	27.53	—	29.82
Torch-Ramrod	0.11	—	—	—	0.11
Torch	0.71	—	—	—	0.71
South Pine	1.38	—	—	0.07	1.45
North Pine	1.81	—	—	0.01	1.82
Spanish Harbor	0.27	—	—	0.79	1.06
Ohio-Bahia Honda	—	0.77	—	—	0.77
Missouri-Little Duck	0.71	0.21	—	—	0.92
Seven-Mile	0.09	13.16	2.21	—	15.46
Tom's Harbor	3.18	—	5.10	—	8.28
Tom's Harbor Cut	0.35	—	—	—	0.35
Long Key	1.70	—	5.62	—	7.32
Channel 5	2.11	—	1.43	—	3.54
Channel 2	0.57	—	—	—	0.57
Lignum Vitae	0.10	—	—	—	0.10
Indian Key	—	—	1.37	—	1.37
Whale	0.23	—	—	—	0.23
Snake	0.03	—	—	—	0.03
TOTAL	24.59	16.25	45.71	5.71	93.33

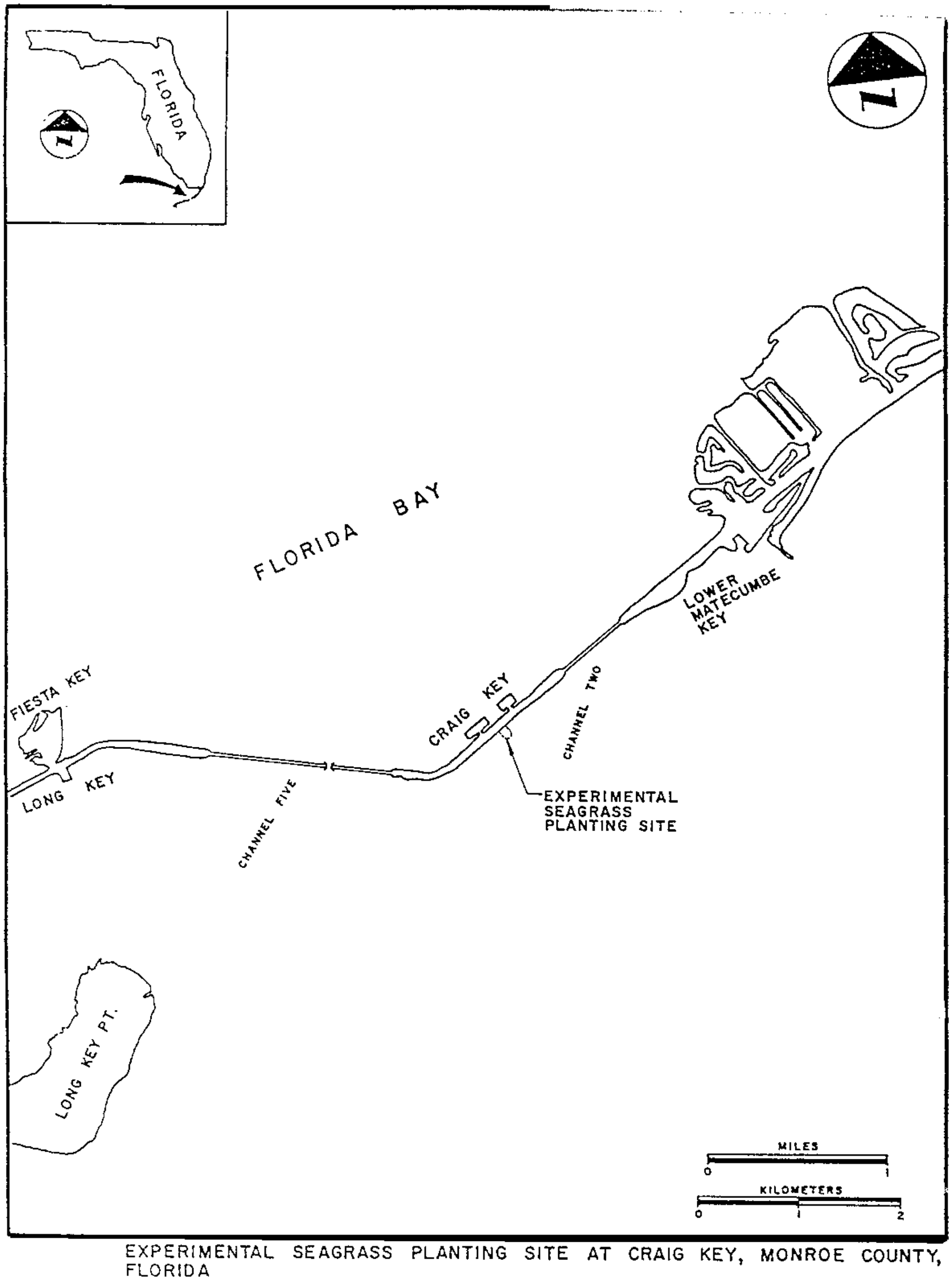
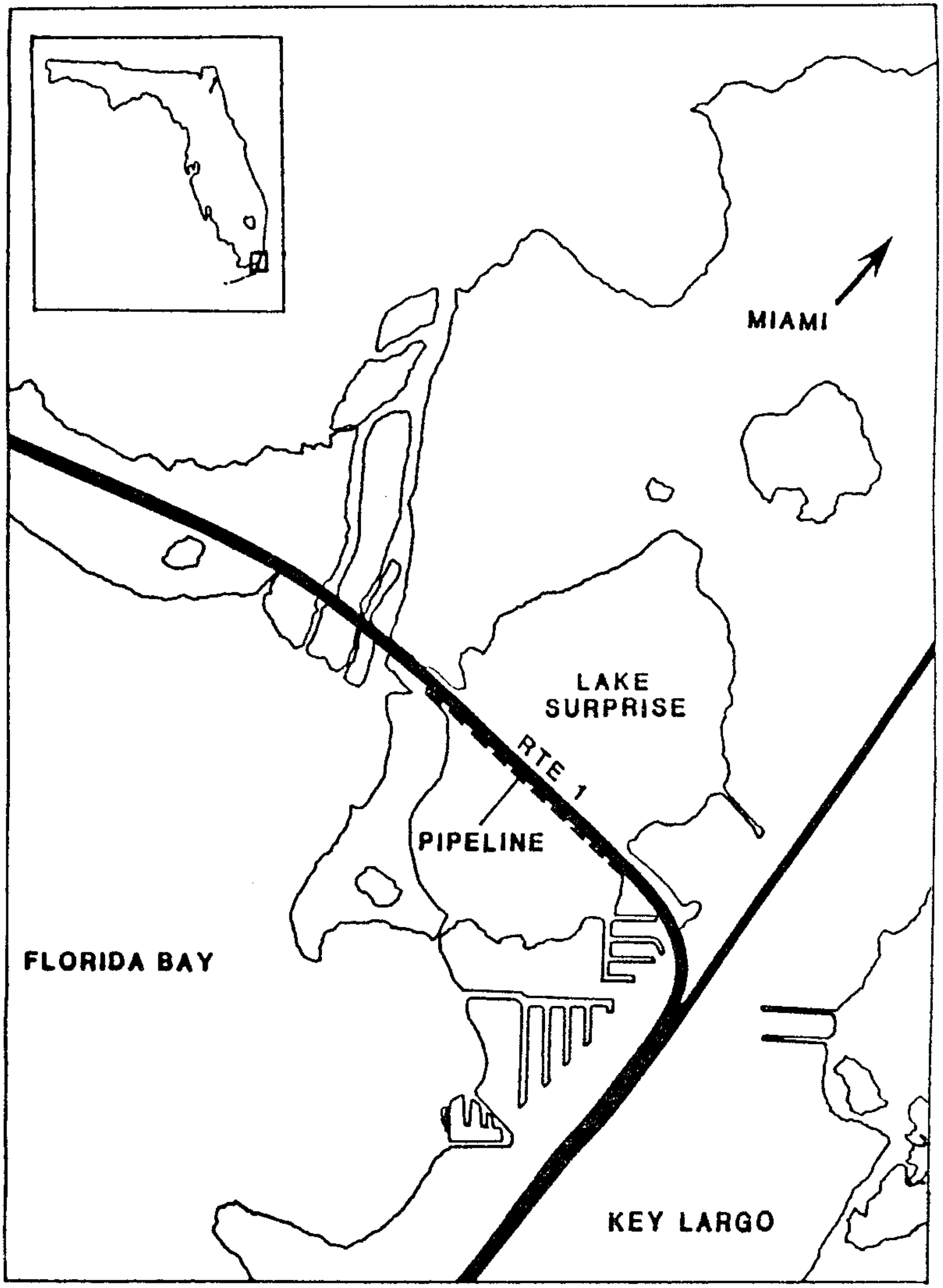


Figure 24. From CSA 1982.



LOCATION OF LAKE SURPRISE

Figure 25. From Derrenbacker and Lewis 1983.

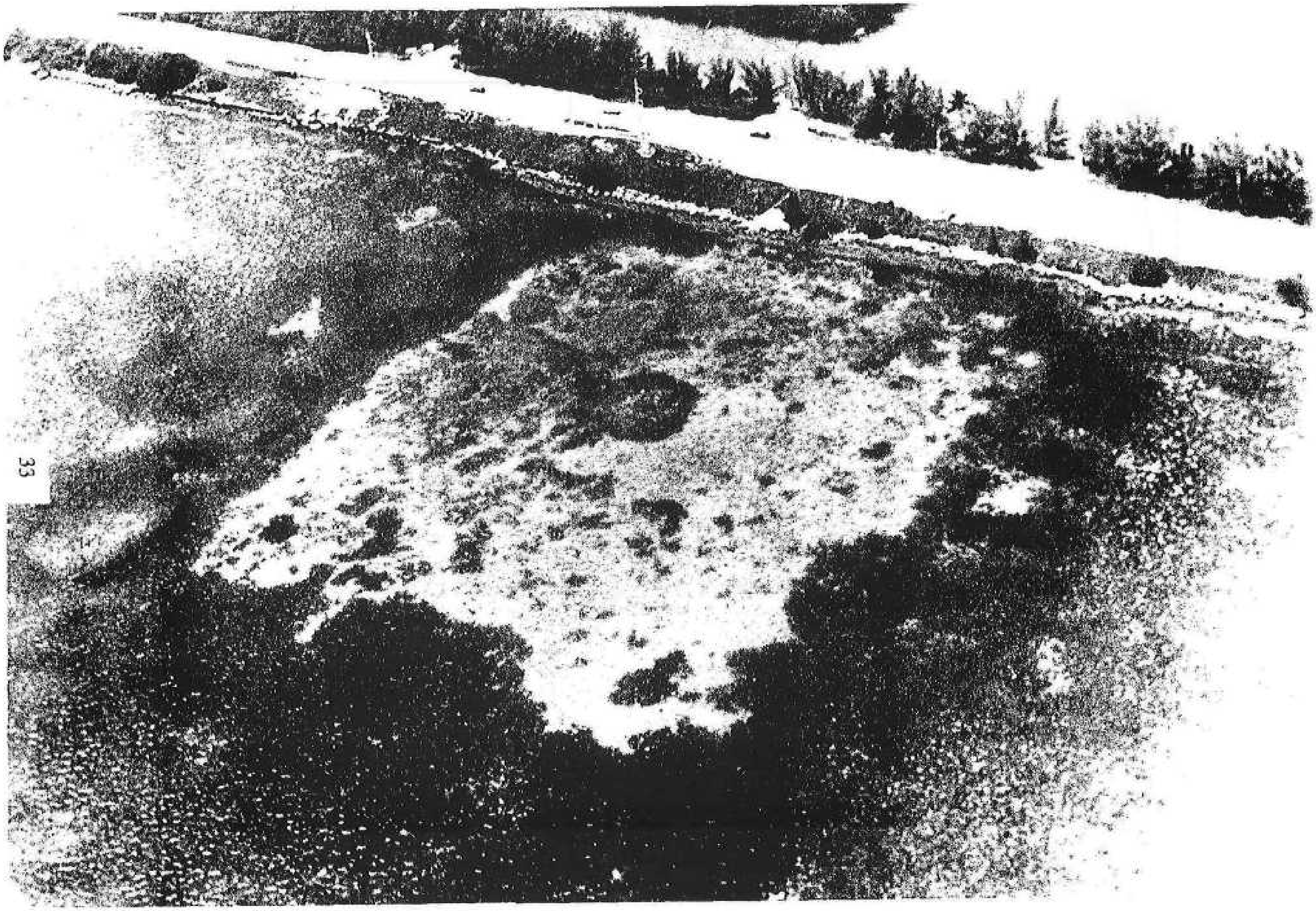
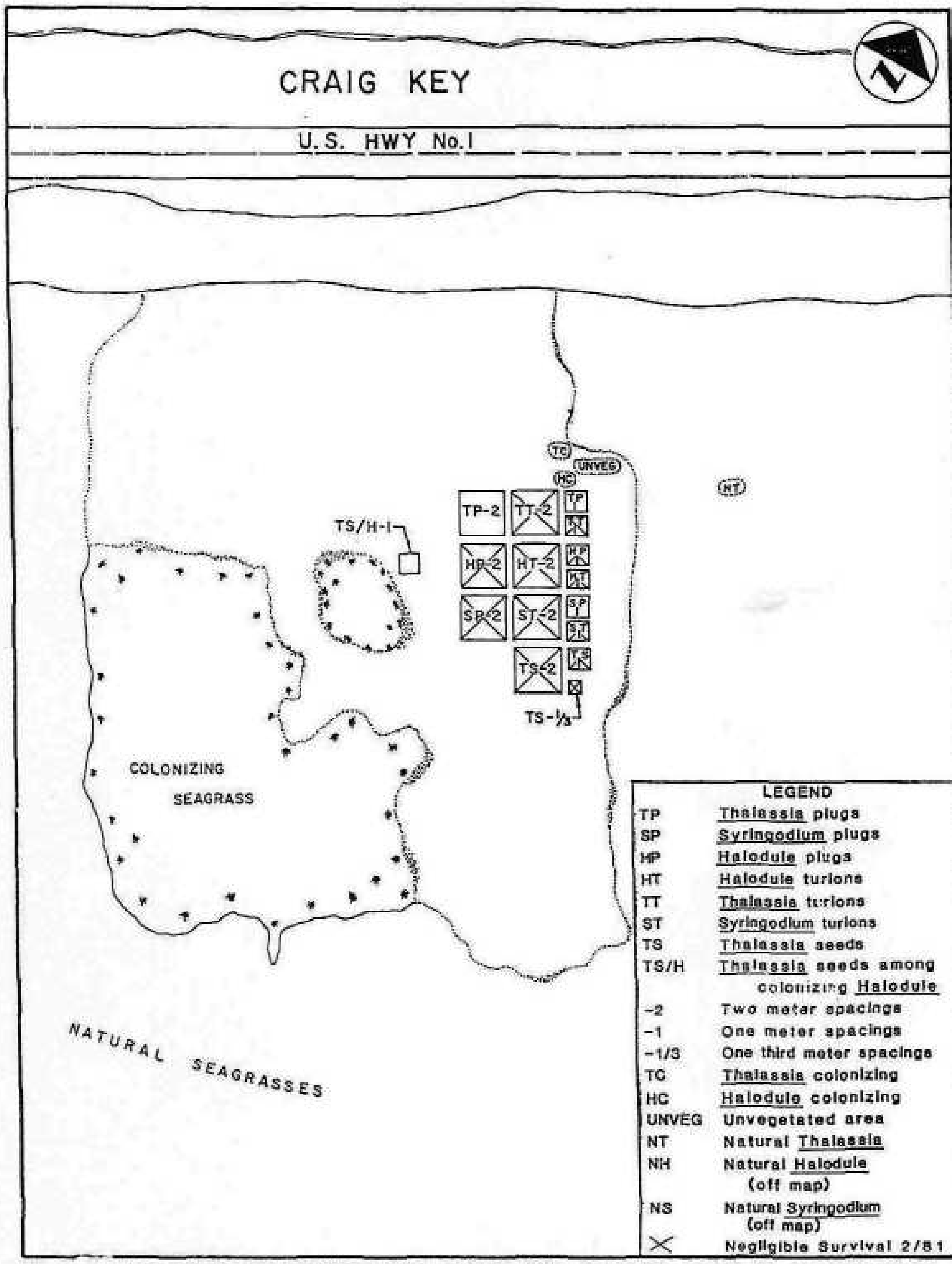


FIGURE 26. Oblique aerial photograph taken August 15, 1980, of the Craig Key seagrass restoration site.



LOCATION OF TRANSPLANT PLOTS AND CONTROL SITES IN EXPERIMENTAL SEAGRASS PLANTING SITE WHICH WERE ORIGINALLY PLOTTED IN FEB. 1979

Figure 27. From CSA 1982.

Figure 28. Thalassia plot TP-1, Craig Key

A. February, 1979

B. August, 1980

C. July, 1981

D. October, 1993

Spacing of 2 m, 1 m, or 0.33 m was obtained by planting the units at points identified by tying marked lines between the corner stakes and then between the lines connected the corner stakes. All lines were removed after planting was completed. The corner stakes, which protruded approximately 15 cm from the bottom, were marked with identification tags and left as permanent plot markers (Figure 28). Elevation stakes were placed within each 1-m-spaced plot for elevation determinations. Elevations of these stakes relative to MSL were determined by relating them to a USGS benchmark, using standard survey techniques. Plots were monitored regularly over 24 months (Lewis 1987). An additional year of data was collected by Lewis and Phillips (1981) and is presented in Table 5.

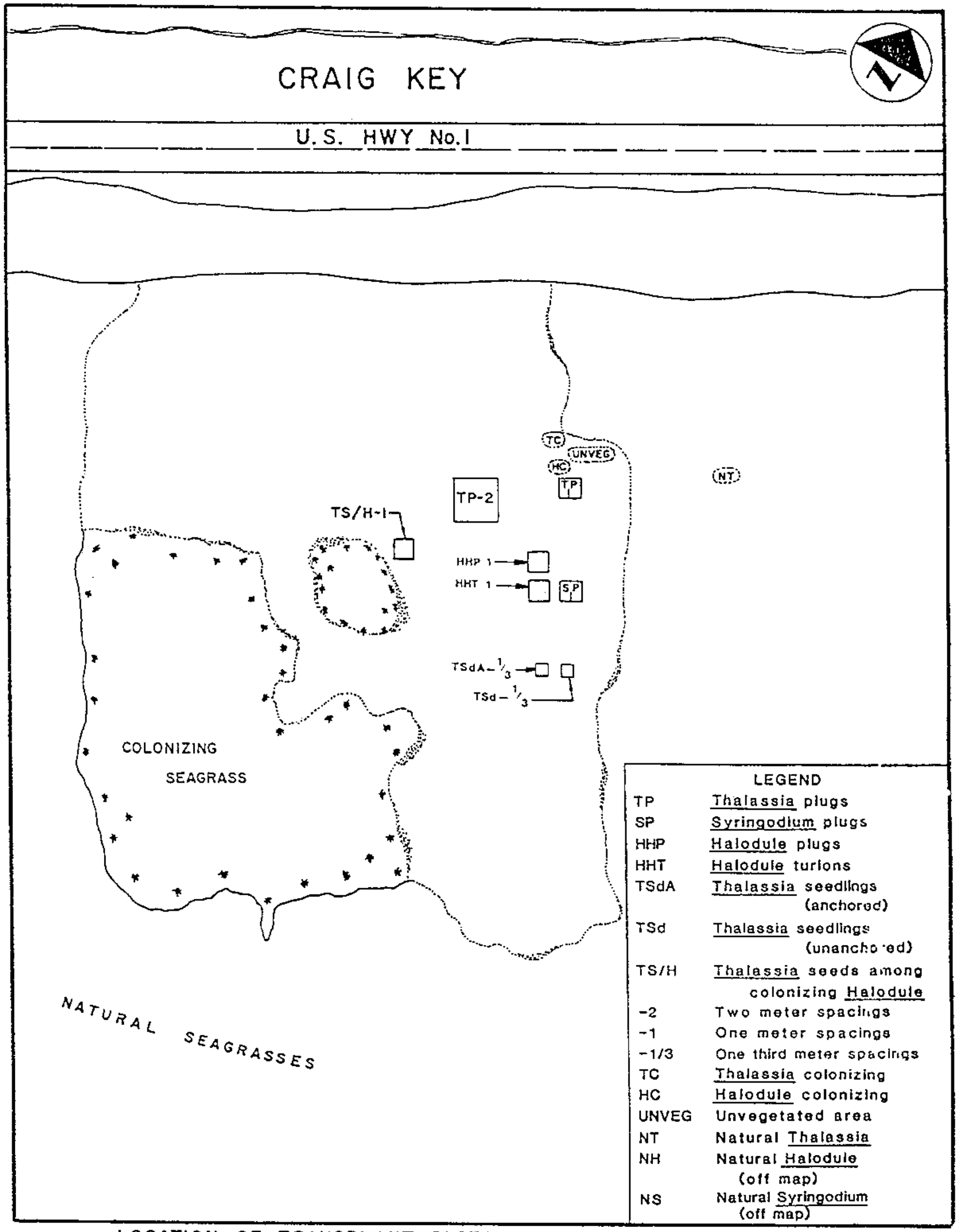
In all instances, plug material showed greater survival than sprigs, regardless of spacing (Figure 29). Of all the plugs planted, *T. testudinum* plugs exhibited the best survival rate. This probably reflects the difference in the total amount of sediment moved with the plant material. Survival of sprigs was approximately the same for all species for the first 6 months; however, all the sprig plantings eventually failed.

Although *T. testudinum* plug survival was greater than that of other species, the observed spread of both *H. wrightii* and *S. filiforme* was greater than that of *T. testudinum*. Coalescence (meeting of spreading rhizomes from adjacent planting units) occurred in *Halodule* plots within 6 months, and in *Syringodium* plots within one year, but not in the *Thalassia* plug plots until 18 months after planting (Figures 28, 30, 31).

Table 5. Craig Key planting unit survival. 49 units were planted in each plot. Percentages refer to percent cover following coalescence. Plots TS-1, TS-⅓ and TS/H-1 were planted in August 1979; plots HHP-1 and HHT-1 were planted in February 1980 (from Lewis 1987).

		NUMBER SURVIVING				
PLOT	UNITS — SPACING (m)	8/79	2/80	8/80	2/81	2/82
TP-1	*Thalassia* plugs — 1	49	48	48	48	48
TT-1	*Thalassia* sprigs — 1	19	5	0	0	0
HP-1	*Halodule* plugs — 1	33	0	0	0	0
HT-1	*Halodule* sprigs — 1	14	1	1	0	0
SP-1	*Syringodium* plugs — 1	30	35%	75%	75%	75%
ST-1	*Syringodium* sprigs — 1	49	14	0	0	0
TP-1	*Thalassia* plugs — 2	39*	37*	48*	44	44
TT-2	*Thalassia* sprigs — 2	9	0	2	0	0
HP-2	*Halodule* plugs — 2	24	0	5	0	0
HT-2	*Halodule* sprigs — 2	14	0	0	0	0
SP-2	*Syringodium* plugs — 2	30	4	25%	0	0
ST-2	*Syringodium* sprigs — 2	7	3	0	0	0
TS-2	*Thalassia* seedlings — 2	49	0	1	0	0
TS-1	*Thalassia* seedlings — 1	49	9	0	3	0
TS-⅓	*Thalassia* seedlings — ⅓	49	0	0	0	0
TS/H-1	*Thalassia* seedlings in *Halodule* — 1	49	0	9	9	7
HHP-1	*Halodule* plugs — 1	—	49	49	50%	30%
HHT-1	*Halodule* sprigs — 1	—	49	21	2	0

*increase in survival number is an artifact of more complete sampling initiated in August 1980.



LOCATION OF TRANSPLANT PLOTS AND CONTROL SITES IN EXPERIMENTAL SEAGRASS PLANTING SITE WITH SURVIVING TRANSPLANTS IN FEBRUARY 1981

Figure 29. From CSA 1982.

Figure 30. Syringodium plot SP-1, Craig Key

A. February, 1979

B. August, 1979

C. July, 1981

D. October, 1993

Figure 31. Halodule plot HHP-1, Craig Key.

A. February, 1980

B. August, 1980

C. July, 1981

D. October, 1993

Of the 18 planting/methodology combinations tested, only three proved successful (Figure 29, Table 4). All three involved the transplanting of large (22 cm x 22 cm) intact plugs of seagrass. *Thalassia testudinum* plugs spaced at 1 m showed 98% survival after 36 months; those spaced at 2 m showed 90% survival. Survival of *S. filiforme* plugs spaced at 1 m was lower (61%, Table 4), but coalescence had occurred by 12 months after planting (Figure 30). Bioturbation by large, burrowing callianassid shrimp was possibly a major factor limiting seagrass survival. Thorhaug (1979) also felt that bioturbation was a factor contributing to the loss of *Thalassia* seedlings. Suchanek (1983, p. 281) has since shown experimentally that "transplants of turtle grass ... into regions of high ... *Callianassa* density produced a dramatic deterioration of *Thalassia* within 2-4 months."

A second planting at Craig Key took place during Phase II of the Florida Keys Seagrass Restoration Project August 13-20, 1983. Approximately 1,000 bare root planting units of *Syringodium* were installed in a 0.25-acre bare area using 6" staples. Monitoring indicated that none of the units were visible in the monitoring plots after one month and none appeared at the one-year monitoring time (Mangrove Systems, Inc. 1985).

Monitoring for this report took place on four occasions during 1993 in an attempt to (a) prepare a detailed map of the seagrass distribution in the borrow pit, and (b) determine if any of the plantings had survived over the 14-year period since the initial plantings. Figures 32 and 33 are aerial photographs showing the Craig Key site in 1981 and 1991, respectively. Figure 34 shows the results of the 1993 mapping compared to a vegetation map based on 1979 photography.

The 1993 mapping (Figure 34) indicates that the 3.4-acre borrow pit, which originally (1979) had a total seagrass cover of only 25% (21.8% *Halodule*, 3.3% *Thalassia*) with 74% cover by algae and bare sand, had achieved 58.9% cover by seagrass in 1993 (39.8% *Thalassia*, 14.7% *Halodule* and 4.4% *Syringodium*); algae and bare sand area was reduced to 41.1% (Figure 34). Exactly how much of this increase was due to planting and how much to natural recolonization cannot be determined. Only two of the eight planted test plots could be definitively located during the monitoring. These were the SP-1 plot (*Syringodium* plugs on one meter centers, Figure 30D) and the TP-1 plot (*Thalassia* plugs on one meter centers, Figure 28D).

These two plots could be located because the SP-1 plot has been relocated (by the senior author) at least annually since its initial planting in 1979 during other work assignments in Monroe County. One of the four unique corner marking posts (the one visible in Figure 31A) has been maintained at the southwest corner of the plot since 1979. The posts are unique in that even without the marked tag they are identifiable by the holes drilled in the side. Knowing this was the southwest corner of that plot, an underwater measuring line was placed between it and the shore to determine where the inshore patches of *Thalassia* began. The *Thalassia* patch visible in Figure 34 (with star) directly north of the *Syringodium* area (with star) begins exactly where one would expect to encounter *Thalassia* originating from the TP-1 planting. In addition, a stake with the unique extra hole was located in the patch. While this is not definitive, it generally supports the "planted" origin of this plot.

Figures 32-33.

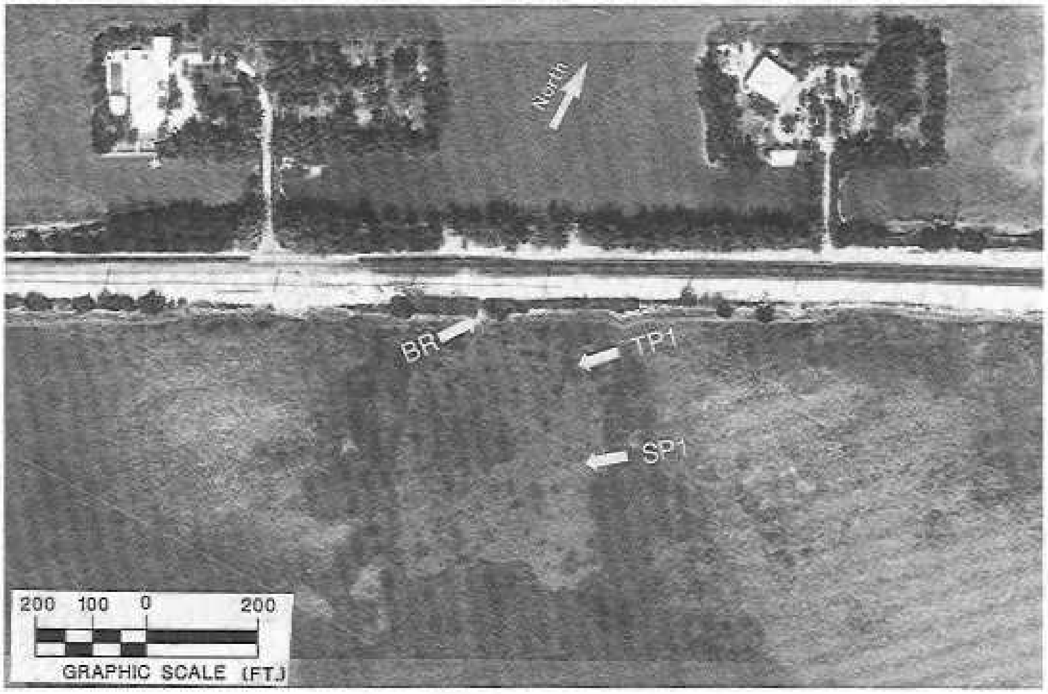


Figure 32. Vertical aerial photography taken February 25, 1981, of the Craig Key seagrass restoration site. Three reference points (BR, SP1 and TP1) are marked for reference to the 1991 photograph below.

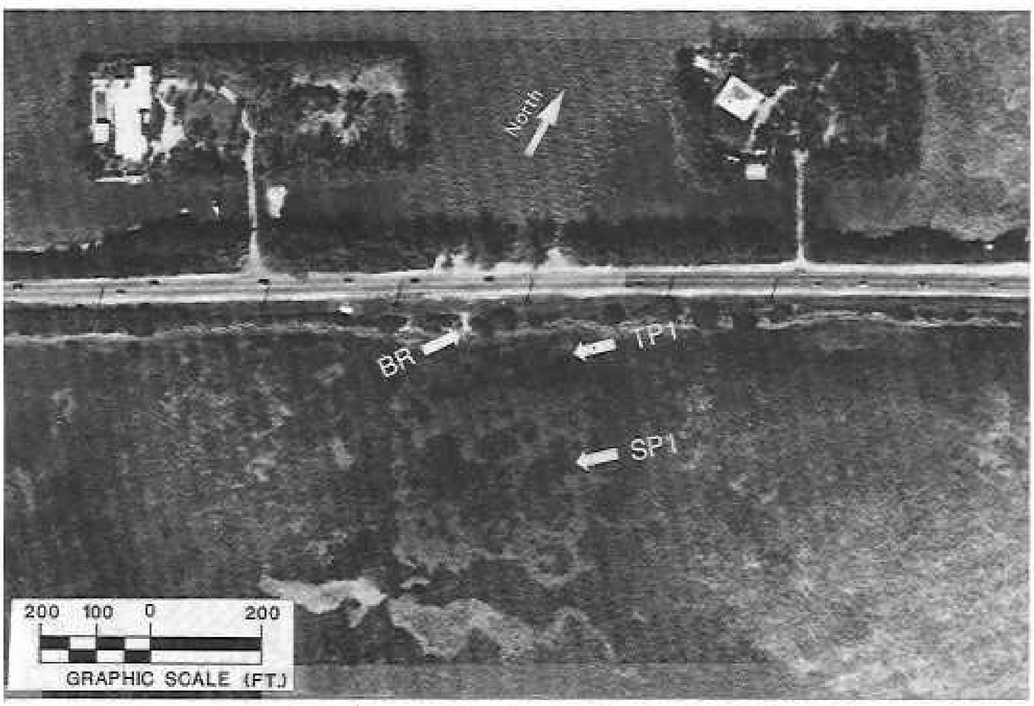


Figure 33. Vertical aerial photography taken February 12, 1991, of the same site as described above. The same three reference points are marked.

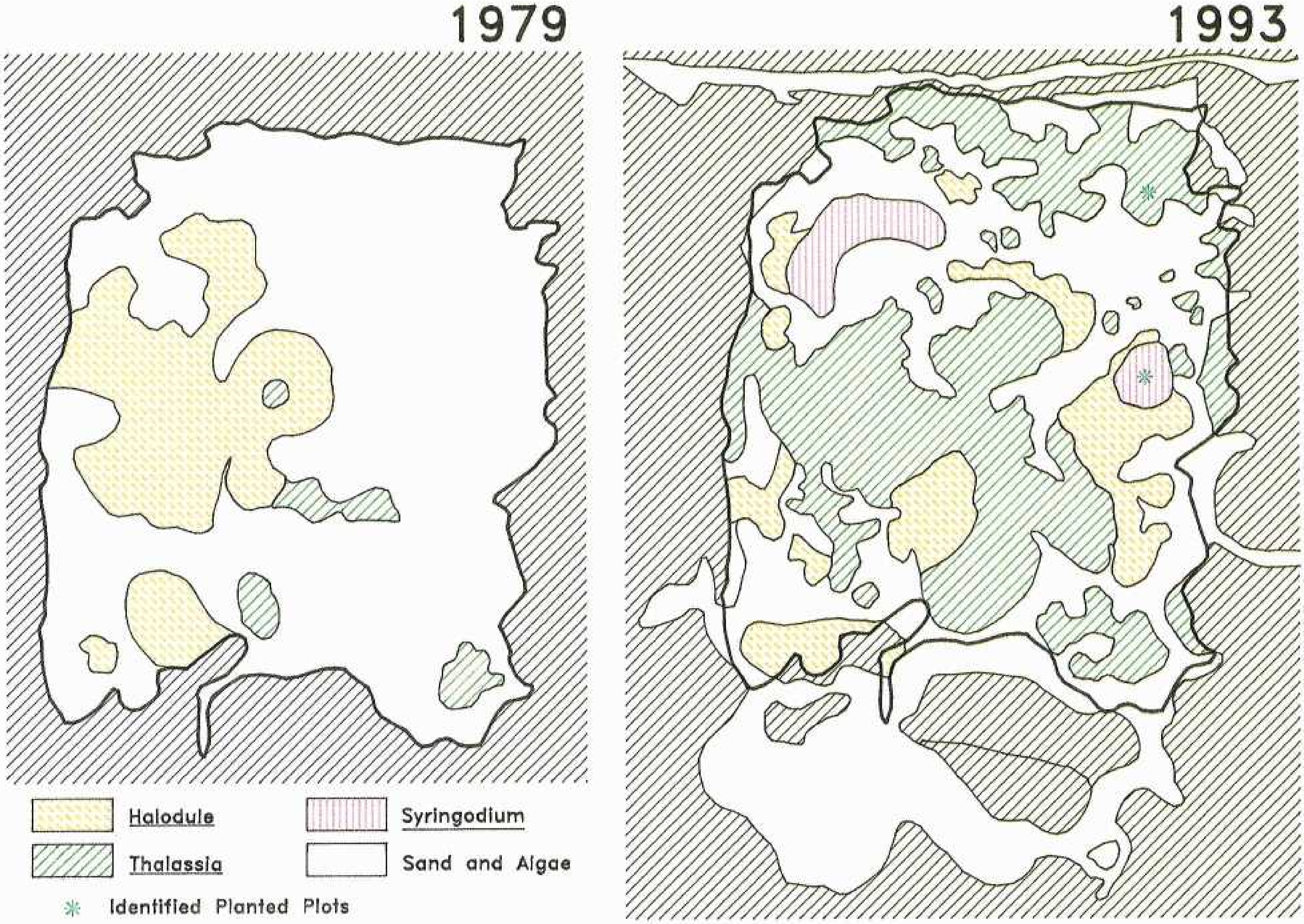


Figure 34. Submerged aquatic vegetation maps of Craig Key, 1979 and 1993.

As to the origin of the balance of the "new" seagrass, it is likely that at least some of the several thousand seagrass units (seeds and seedlings) installed between 1979 and 1983 and subsequently "lost" did not die or leave the site due to currents, but simply were relocated by activities in the pit. It has been observed over the years that the pit is a popular shoreside fishing site, small boat launching point, swim, dive and snorkel area, and frequent crossing point for boats traveling in the area.

Thus routine disturbance is normal, and catastrophic disturbance (i.e. prop cutting at low tide) at least a possibility. A buoy placed at the SP-1 site as part of this study has had its mooring line cut twice and its anchor pulled up several times.

Lake Surprise

In 1981, the Florida Keys Aqueduct Authority was authorized to place a new, large water pipeline through the Keys. A section of the pipeline was to run through Lake Surprise, next to U.S. Route 1, which bisects the lake northeast of Key Largo (Figure 25). Subsequent pipeline construction, in early 1981, resulted in the destruction of approximately 5 acres of natural seagrass beds (mostly *T. testudinum*) and alteration of the sediment and topography. This alteration of the lake required mitigation by the construction company, under the supervision of the Florida Department of Environmental Regulation (Derrenbacker and Lewis 1983).

The pipeline construction left two types of impacted areas (Figure 35): a "moderately" impacted area, located along either side of a "severely" impacted strip. The moderately impacted area still had the original water depth (1 m), sediment type (shell hash), and topography, but the seagrass had been removed. This area had not been excavated, but had been disturbed by construction activities. The severely impacted area had been completely excavated to a depth of about 4 m below MSL; the 1-m-diameter pipeline was installed, and the area was backfilled (June 1981). After construction, this area was generally deeper (1.5-3 m), irregular in topography, and consisted mainly of two types of substrate: one was an unstable, fine, silty sediment up to 1 m deep; the other consisted of limestone rubble of various sizes.

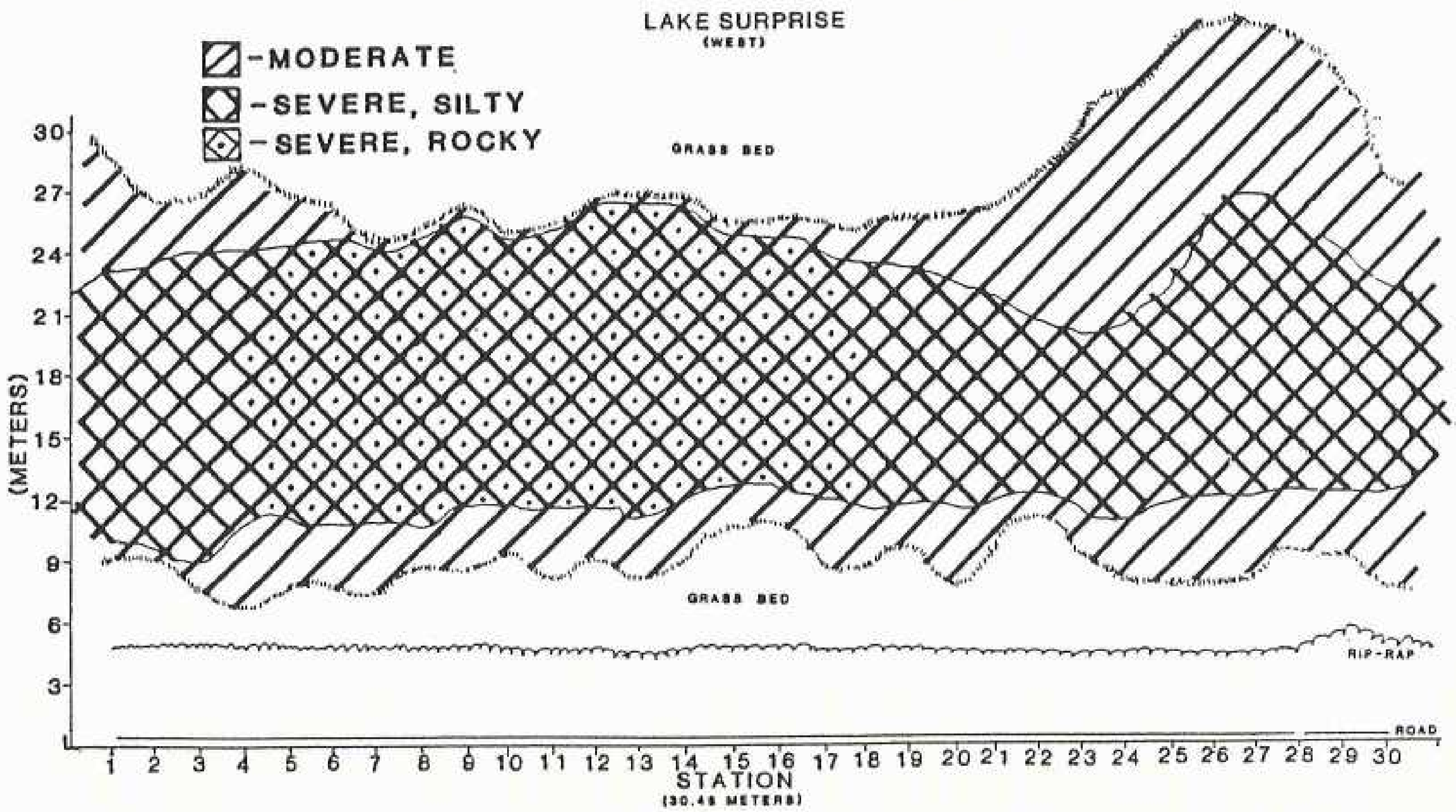
These methods of seagrass planting were evaluated in this area (Figure 36):

1) 15-cm long steel staples were used to anchor 10-30-cm long runner sections of *H. wrightii* on 0.6 m centers over a 3.36-acre planting area (36,700 planting units);
2) 50,000 *T. testudinum* seedlings were hand broadcast over an approximately 1.08-acre area for about 0.3-m center coverage;
3) 300 sections of *Thalassia* rhizomes with attached short shoots were transplanted over 0.47 acre on approximately 0.3 m centers.

Total labor requirements were 150 manhours per acre (mh/ac) for *Halodule*, 100 mh/ac for *Thalassia* seedlings, and 52 mh/ac for *Thalassia* rhizomes with short shoots.

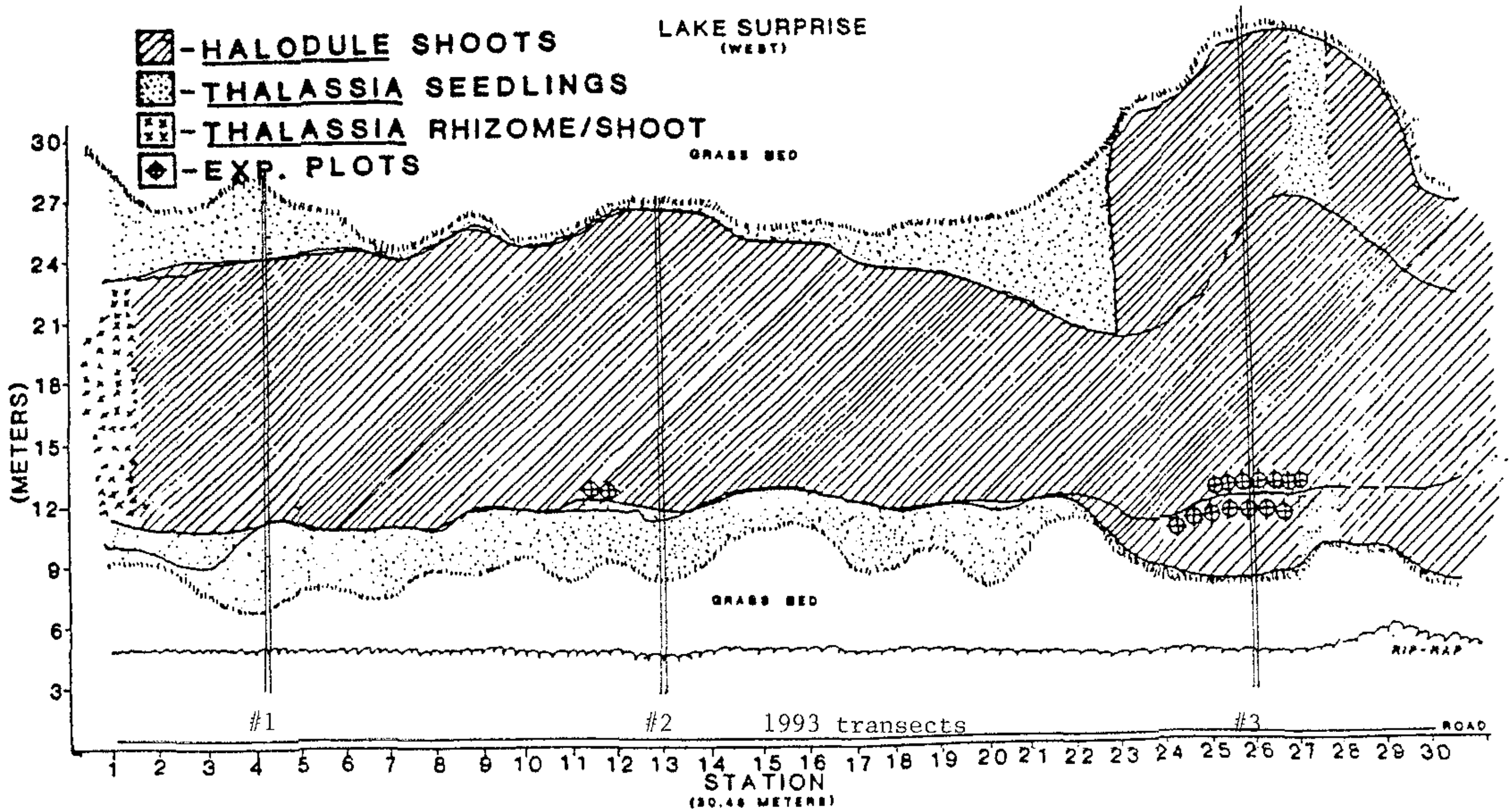
Planting occurred in three types of areas:

1) *Halodule wrightii* planted in a moderately impacted shell hash area, a severely impacted fine silt area, and a severely impacted rocky area;
2) *Thalassia* seedlings broadcast over moderately impacted areas;
3) *Thalassia* rhizomes with short shoots planted in a severely impacted fine silt area.



LOCATION OF MODERATELY AND SEVERELY IMPACTED AREAS

Figure 35. From Derrenbacker and Lewis 1983.



AREAS TRANSPLANTED WITH HALODULE AND THALASSIA
BY MANGROVE SYSTEMS, INC.

Figure 36. From Derrenbacker and Lewis 1983.

In addition, 16 experimental plots (each 2 m x 2 m) were planted with various species combinations, in the three types of area, and monitored.

After 7 months, *H. wrightii* had attained 100% coverage in the moderately impacted area, 98% in the severely impacted fine silt area, and 18% in the severely impacted rocky area. *T. testudinum* seedlings had attained a 55% survival rate in the moderately impacted area and a 44% survival rate in the severely impacted fine silt area. *Thalassia* rhizomes with short shoots attained a 75% survival rate in both areas (Derrenbacker and Lewis 1983).

Lake Surprise was inspected twice during this study. The first inspection was merely for reconnaissance, and the second (November 5-6, 1993) included photographing three transects at 4 m, 13 m and 26 m stations (Figure 36).

It is apparent from the data (Tables 6 and 7) and the associated photographs (Figures 37-39) that eleven years after restoration, the site is still vegetated with only approximately 40% turtle grass, similar to what was present prior to pipeline installation (15 of 38 stations; Figures 37 and 38). The rapid growth of planted *Halodule* observed by Derrenbacker and Lewis (1983) has stalled at an intermediate stage of succession and full recovery can be expected only after another ten years, and then probably only in the moderate to moderate and silty areas (Figure 35). It is also apparent that some continued disturbance of the area is occurring with seagrasses being "blown-out", probably by wave runners known to use the area (Figure 38A). The failure to completely restore the original level of sediment over the rocky substrate encountered during construction will probably limit the degree of final recovery in these areas of sparse to dense *Halodule* with sparse *Thalassia,* if present at all. This may mean that the area could be a candidate for backfilling with additional sediment and seagrass from impacts associated with the widening of U.S. Highway 1 in the area where approximately 10 acres of *Thalassia* are to be destroyed by excavation or filling.

Table 6. Lake Surprise seagrass short shoot density, November 1993.

	Number of short shoots per m^2					
	STATION 4		STATION 13		STATION 26	
SITE (m)	*Thalassia*	*Halodule*	*Thalassia*	*Halodule*	*Thalassia*	*Halodule*
6	0	0	0	0	1200	0
9	300	0	2300	0	1000	0
12	900	0	1300	0	0	0
15	0	200	200	500	1200	0
18	0	0	0	300	100	0
21	0	0	0	300	0	100
24	400	0	700	200	0	100
27	0	500	0	500	600	100
30	0	500	0	600	500	300
33	0	400	200	0	800	0
36	0	400	0	800	0	300
39	0	1000	0	300	0	300
42	0	500	0	700	0	0

Table 7. Seagrass abundance, Lake Surprise, November 1993.

		SEAGRASS ABUNDANCE			ALGAE ABUNDANCE								
STATION	SITE (m)	T	H	S	A	B	C	K	L	M	P	U	V
4	6	2	+	—	—	2	+	—	2	2	+	—	—
	9	4	+	—	—	—	—	—	—	2	—	—	—
	12	5	—	1	—	—	—	—	—	1	—	—	—
	15	—	+	—	—	—	—	—	—	2	+	—	—
	18	—	+	—	—	+	—	—	—	2	+	—	—
	21	—	+	—	—	—	—	—	—	2	2	+	—
	24	3	—	—	+	—	—	—	—	2	+	+	—
	27	+	1	—	—	—	—	—	—	—	+	—	—
	30	—	2	—	—	—	—	—	—	—	—	—	—
	33	—	2	—	—	—	—	—	—	2	—	—	—
	36	—	1	—	—	—	—	—	—	1	—	—	—
	39	—	2	—	—	—	+	—	—	—	—	—	—
	42	—	2	—	—	—	—	—	—	—	—	—	—
13	6	+	—	—	—	—	—	—	—	—	—	—	—
	9	4	—	—	—	—	—	—	—	—	—	—	—
	12	4	+	—	—	—	—	—	—	+	—	—	—
	15	+	+	—	—	—	—	—	—	—	—	—	—
	18	—	+	—	+	—	—	—	—	1	—	—	+
	21	+	1	—	—	—	—	—	—	2	—	—	—
	24	3	+	—	+	—	—	—	—	2	+	—	—
	27	—	2	—	—	—	—	—	—	—	+	+	—
	30	+	2	—	—	—	—	—	—	+	—	—	—
	33	+	+	—	—	—	—	—	—	1	—	—	—
	36	+	1	—	—	—	—	—	—	—	—	—	—
	39	—	1	—	—	—	—	—	—	1	—	—	—
	42	—	2	—	—	—	—	—	—	1	—	—	—
	NOTE: *Thalassia* bed encountered at 44 m												
26	6	5	—	—	—	—	1	+	2	+	—	—	—
	9	5	—	—	—	—	+	—	1	—	—	—	—
	12	(bare bottom)			—	—	—	—	2	—	—	—	—
	15	4	+	—	—	—	—	—	4	—	—	—	—
	18	—	+	—	—	—	—	—	—	—	—	+	—
	21	—	+	—	—	—	—	—	—	—	—	+	—
	24	—	+	—	—	—	—	—	—	+	—	—	—
	27	3	+	—	—	—	—	—	—	1	—	—	—
	30	4	—	—	—	—	—	—	2	—	—	—	—
	33	5	—	—	—	—	—	—	—	—	—	—	—
	36	—	2	—	—	—	—	—	—	—	+	—	—
	39	+	1	—	—	—	—	—	—	—	—	—	—
	NOTE: *Thalassia* bed encountered at 40 m												

Braun-Blanquet scale for spatial abundance: + = sparse; 1 = <5% cover; 2 = 5-25% cover; 3 = 25-50% cover; 4 = 50-75% cover; 5 = 75-100% cover. T — *Thalassia*; H — *Halodule*; S — *Syringodium*;
A — *Acetabularia*; B — *Batophora*; C — *Caulerpa*; K — *Chaetomorpha*; L — *Laurencia*; M — *Halimeda*;
P — *Penicillus*; U — *Udotea*; V — *Avrainvillea*

Figure 37A. Lake Surprise, transect 1, 4-5 m from shore, November 1993.

Figure 37B. Lake Surprise, transect 1, 10-11 m from shore, November 1993.

Figure 38A. Lake Surprise, transect 2, 3-4 m from shore, November 1993.

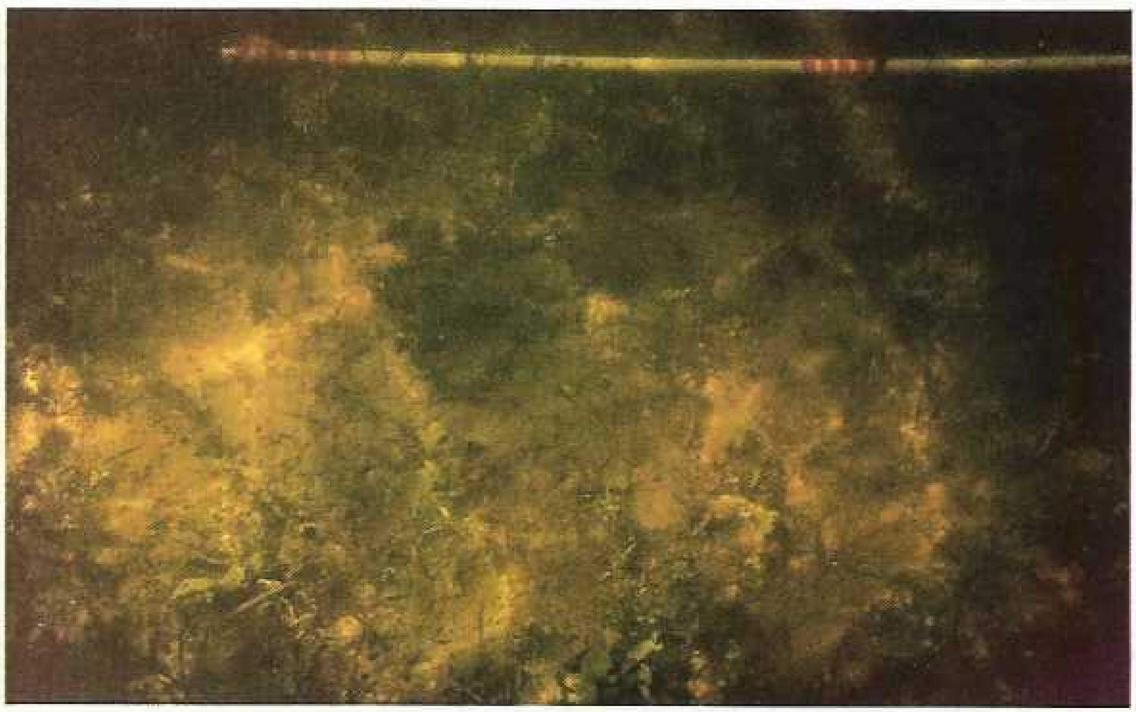


Figure 38B. Lake Surprise, transect 2, 11-12 m from shore, November 1993.

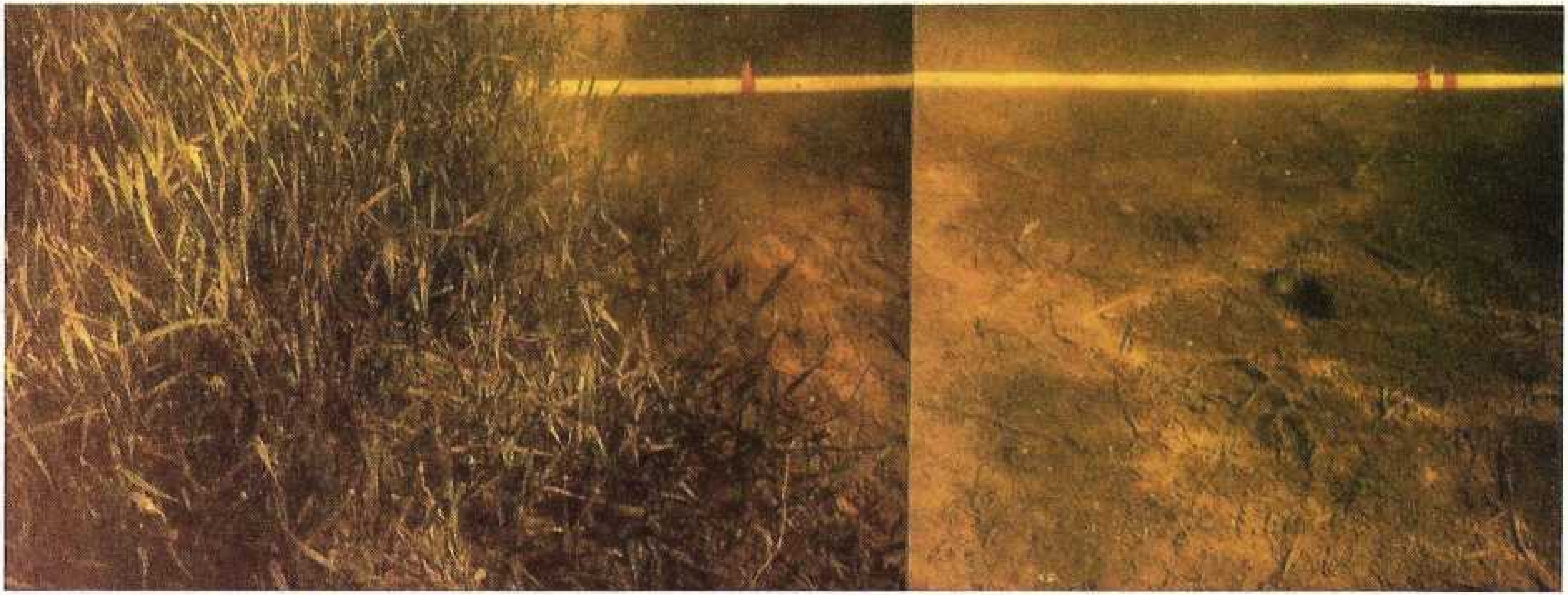


Figure 39. Composite underwater photographs of the Lake Surprise seagrass restoration area, transect 3, 7-9 m from shore, November 1993.

Florida Keys Seagrass Restoration Project

The Florida Keys Seagrass Restoration Project resulted from two modifications (Appendixes C and D) to the original Memorandum of Agreement (Appendix B) concerning Keys mitigation. Seagrass restoration was executed in two phases (Table 8). both phases were supervised by Mangrove Systems, Inc., under contract to the department of Environmental Regulation and using $150,000 of the $200,000 given to DER by FDOT (Appendix D) to resolve its outstanding mitigation requirements.

Phase I occurred during 16-23 April 1983; upon completion, 22.38 acres had been planted over four sites. Planting material consisted of *Halodule wrightii* long shoots, on approximately 1-m centers, anchored to the substrate with either staples or nails.

Phase II occurred during 13-20 August 1983; upon completion, 10.96 acres had been planted over 16 sites (Table 8). Planting methods and materials were consistent with Phase I specifications, with the exception of site 24 (Craig Key), where *Syringodium filiforme* was substituted for *Halodule wrightii*. Only staples were used as anchoring devices due to low survival rates of units anchored with nails.

The combined area planted during both phases totaled 33.34 acres. As of 23 August 1984, a total of 20.43 acres of *Halodule wrightii* had been successfully restored to the required 80% cover. These figures are equivalent to 61.3% survival for combined phases of the Florida Keys Seagrass Restoration Project (Table 8).

Subsequent to Phases I and II, compensatory planting efforts were undertaken by Mangrove Systems, Inc. At Sexton Cove, 14.00 acres were planted. Planting material consisted of *Halodule wrightii* long shoots, on approximately 2 m centers, anchored with staples. Additionally, 0.20 acre of previously unplanted area was revegetated at Boog Powell Marina. Planting material consisted of *Halodule*, on approximately 1 m centers, anchored with staples. Compensatory planting totaled 14.2 acres.

The total area planted during Phase I, Phase II and the compensatory planting was 47.54 acres. The total surviving area meeting contractual requirements of 80% cover was 34.63 acres; these figures are equivalent to 72.8% success.

Figures 40 and 41 show the Boog Powell Marina planting area in 1981 before spit removal and in 1991, eight years after planting. The entire spit, except for a small portion with only a rock substrate, is now predominantly *Syringodium* with lesser amounts of *Halodule*.

While the Boog Powell Marina planting effort was a success, the planting efforts at the 7-Mile Bridge were not. Seven locations of seagrass damage were identified in the initial phases of the project (Table 8, Sites 13-19; Figure 42). These areas totaled 15.36 acres and planting was attempted at four of the sites (D, E, F and G) totaling 6.11 acres. None of the plantings survived. The primary reason for the failure was not apparent until Curtis Kruer, then the U.S. Army Corps of Engineers field biologist in the Keys, noticed that the flotation cuts (excavated parallel to the new bridge alignment to allow barge access for piling installation and subsequent bridge unit placement) were being used as a short cut by

Table 8. Summary of planting, Florida Keys Seagrass Restoration Project (modified from MSI 1985).

	SITE	INITIAL AVAILABLE ACRES	PHASE I PLANTED ACRES	PHASE II PLANTED ACRES	MSI MAKE-UP ACRES	TOTAL PLANTED ACRES	PERCENT SURVIVAL[1] 8/84	ACRES SURVIVING 8/84	ACRES SURVIVING 9/93
1.	Stock Island	15.00	17.00			17.00	100	17.00	15.00
2.	Boog Powell Marina	1.00		1.00		1.00	100	1.00	1.00
3.	Shark Channel	2.11	1.50	0.71		2.21	0	0.00	1.00[3]
4.	Harris Channel	0.46		0.24		0.24	167	0.40	0.40
5.	North Harris Channel	0.49		0.47		0.47	100	0.47	0.47
6.	Park Channel	0.40		0.35		0.35	0	0.00	0.30[3]
7.	Kemp Channel	0.43		0.60		0.60	83	0.50	0.50
8.	Niles Channel	27.53[2]		0.44		0.44	0	0.00	23.22[3]
9.	Torch-Ramrod Channel	0.56		0.10		0.10	100	0.10	0.10
10.	Torch Channel	0.53	—	—	—	—	—	—	0.00
11.	Ohio-Bahia Honda Ch.	0.77	—	—	—	—	—	—	0.00
12.	Missouri-Little Duck	0.21	—	—	—	—	—	—	0.00
13.	Seven-Mile Bridge A	4.08	—	—	—	—	—	—	0.00
14.	Seven-Mile Bridge B	2.21	—	—	—	—	—	—	2.21
15.	Seven Mile Bridge C	0.95	—	—	—	—	—	—	0.62
16.	Seven-Mile Bridge D	3.06		1.42		1.42	0	0.00	0.30[3]
17.	Seven-Mile Bridge E	0.96	0.30	0.96		1.26	0	0.00	0.24[3]
18.	Seven-Mile Bridge F	3.58	3.58			3.58	0	0.00	1.07[3]
19.	Seven-Mile Bridge G	0.52		0.15		0.15	0	0.00	0.26[3]
20.	Tom's Harbor Channel	5.10	—	—	—	—	—	—	5.10[3]
21.	Long Key Channel, West	1.77		1.08		1.08	10	0.11	0.00
22.	Long Key Channel, East	3.85		0.51		0.51	25	0.13	3.85[3]
23.	Channel No. 5	1.43		1.43		1.43	33	0.47	1.00
24.	Craig Key	1.00		0.25		0.25	0	0.00	1.15[4]
25.	Indian Key Channel	1.37		1.25		1.25	20	0.25	0.00
26.	Boca Chica Lagoon	—	—	—	—	—	—	—	62.20[5]
	Subtotals:	79.37	22.38	10.96		33.34	61.3	20.43	119.99
COMPENSATORY PLANTINGS:									
26.	Sexton Cove	14.00			14.00	14.00	100	14.00	14.00
2A.	Boog Powell Spit Tip	0.20			0.20	0.20	100	0.20	0.20
	TOTALS:	93.57			14.20	47.54	72.8	34.63	134.19

[1]percent acreage meeting 80% cover requirement
[2]modified from MSI report with the addition of 27.09 acres of prop dredge damage away from bridge
[3]natural revegetation since 1981
[4]increase in acreage of seagrass since the 1979 plantings, including volunteers
[5]measured increase in seagrass cover since reopening

Figure 40-41.

Figure 40. Vertical aerial photograph of a filled spit near Boog Powell Marina, February 25, 1981.

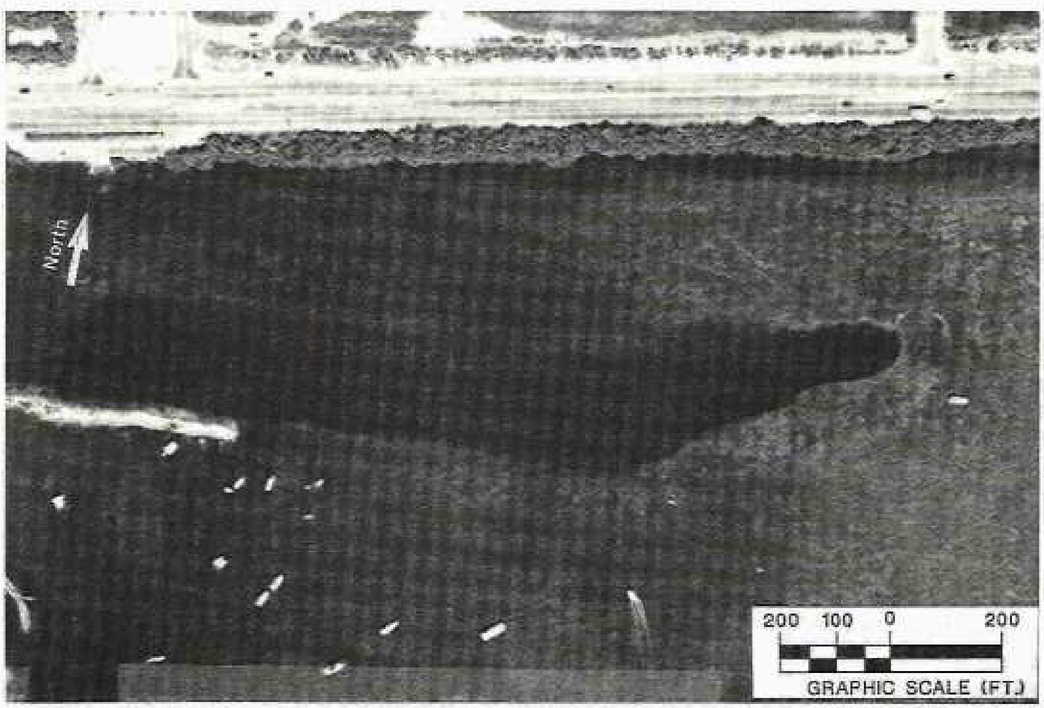


Figure 41. Vertical aerial photograph of the same area after removal of the spit and several planting efforts. Photographed February 17, 1991.

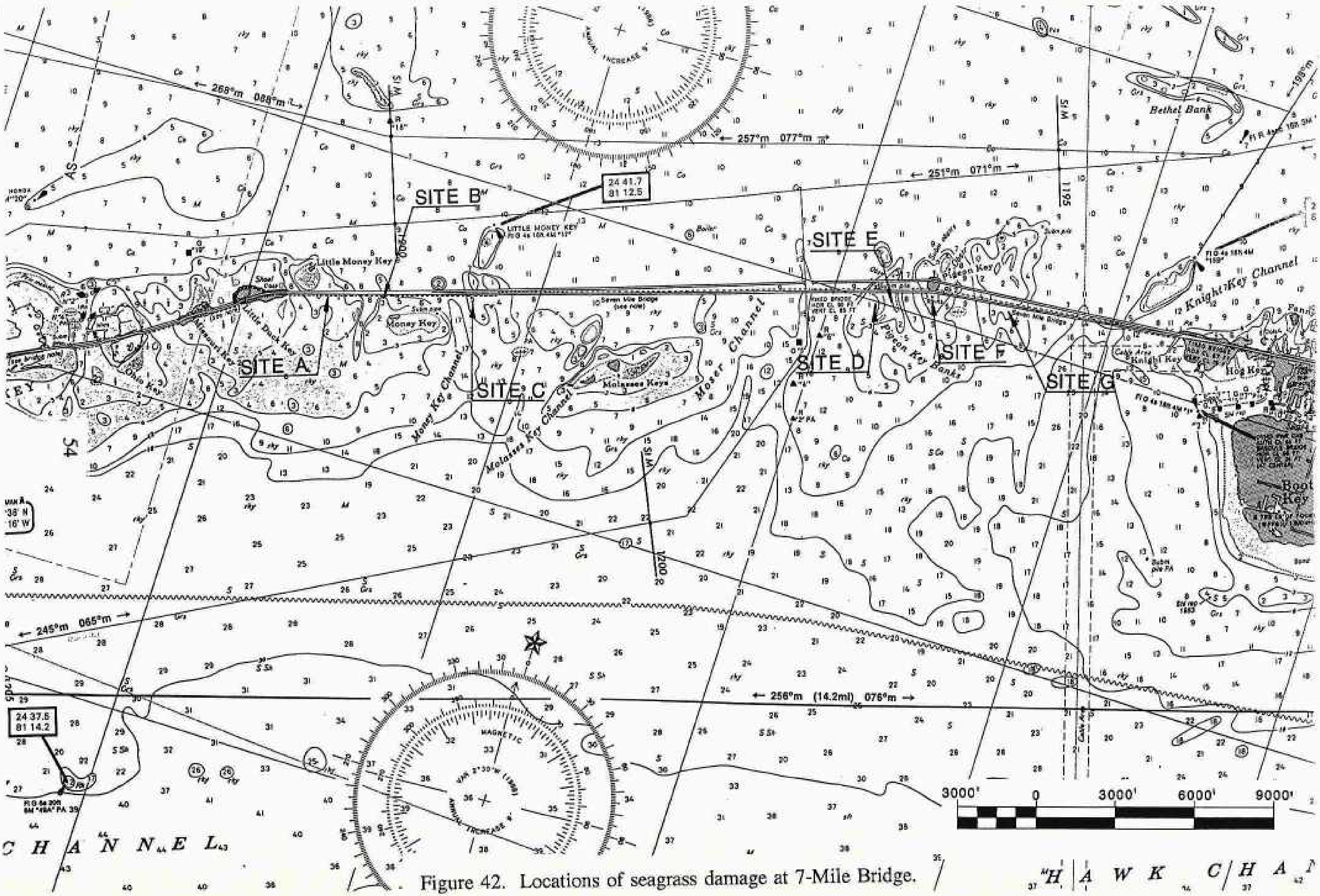


Figure 42. Locations of seagrass damage at 7-Mile Bridge.

fully-loaded commercial lobster boats that were dragging their keels and blowing out the loose sand in the planted cuts as they transported lobster traps for setting prior to the opening of the commercial lobster season. Without total closure of these areas to boat traffic or backfilling to original grade, no significant recovery was predicted when the excavated cuts were monitored in 1984 after planting in 1983. The sites were revisited in June 1993 and examined for natural revegetation in cuts and recovery of the prop cut area at Site B. Site B has recovered nearly completely from the extensive prop cutting (see Section IV).

The following are narrative descriptions of the seven sites inspected in June 1993 and are referenced to data presented in Table 8 and Figures 43-46.

Site A, 4.08 acres excavated
This site was rejected for planting in 1983 because the substrate was essentially rock with little or no overlying sediment. The 1993 inspection indicated its character was much the same, with just a few scattered patches of *Thalassia* and *Halodule,* but no significant recolonization by seagrass has occurred.

Site B, 2.21 acres of prop cuts (see Section IV)

Site C, 0.95 acre of excavation
Approximately 65% cover over the entire area with *Thalassia* and *Syringodium* (0.62 acre recovered).

Site D, 3.06 acres of excavation
Approximately 10% of the site is vegetated with a mixture of *Thalassia* and *Halodule*. Figures 43 and 44 show a comparison of the site in 1981 and 1991. The recovery areas are primarily at RC1 and RC2.

Site E, 0.96 acre of excavation
Approximately 25% of the site is vegetated with *Halodule* only. Mean shoot density was 1,364/m^2. Figures 43 and 44 show a comparison of the site in 1981 and 1991. The recovered seagrass is visible as elongate strips next to the bridge (RC3). The shape of the recovery areas has changed somewhat since 1991.

Site F, 3.58 acres of excavation and fill deposition on adjacent seagrass (Figure 45)
Approximately 30% of the area has revegetated with *Thalassia* in scattered patches in the excavated area, primarily at the west end and the northeast corner (Figure 46). The two predominant blow-outs of sand on the top of the adjacent *Thalassia* have completely revegetated with *Thalassia*. Some *Syringodium* has recolonized under the northeast corner of the cut in the edge of the shadow of the new bridge.

Site G, 0.52 acre of excavation
Approximately 50% of this area has revegetated naturally with both *Syringodium* and *Thalassia*.

Figures 43-44.

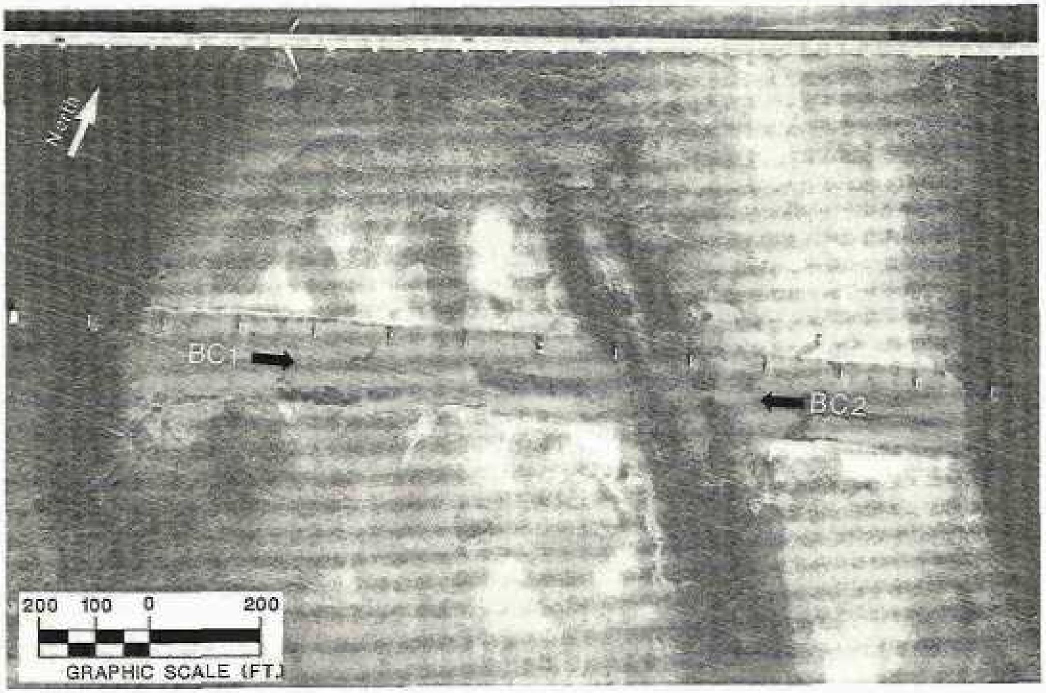


Figure 43. Vertical aerial photograph taken February 25, 1981, showing the Pigeon Key Banks (PKB) east of Pigeon Key. The old 7-Mile Bridge is shown at the top. The alignment of the new bridge is indicated by the excavated barge access channel (BC1-BC2) and the installed pilings. Sites D and E (Figure 42) are shown here.

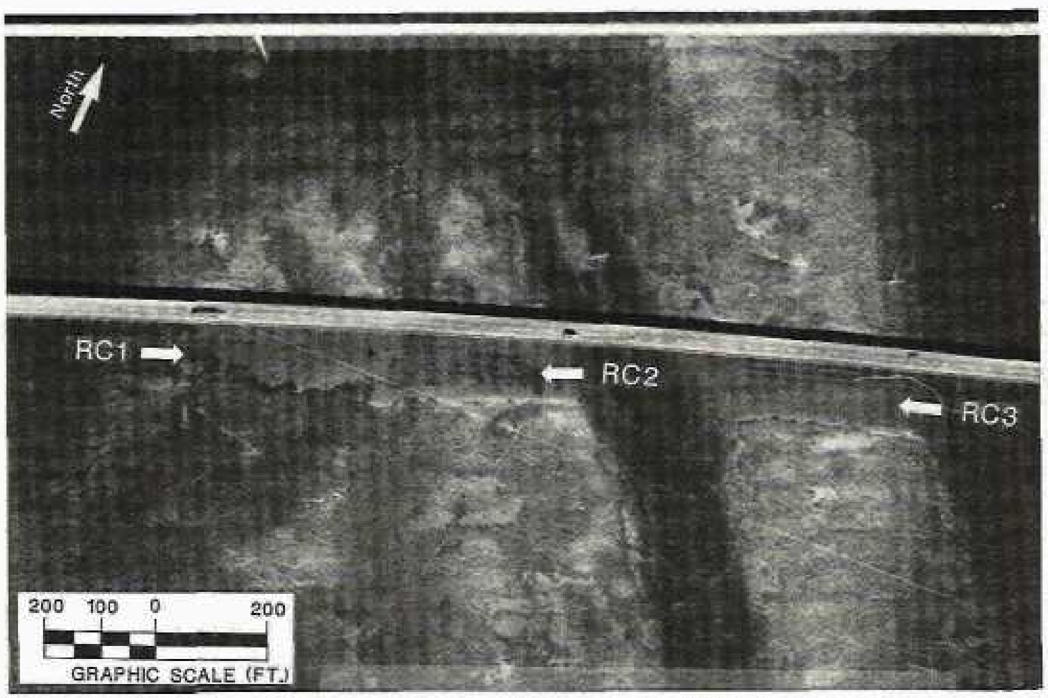


Figure 44. Vertical aerial photograph taken February 12, 1991, showing same area as above. The only significant reclonization of the barge access channel is shown at RC1 and RC2, which were confirmed in the field to be a mixture of *Halodule* and *Thalassia*, and RC3 which was all *Halodule*.

Figures 45-46.

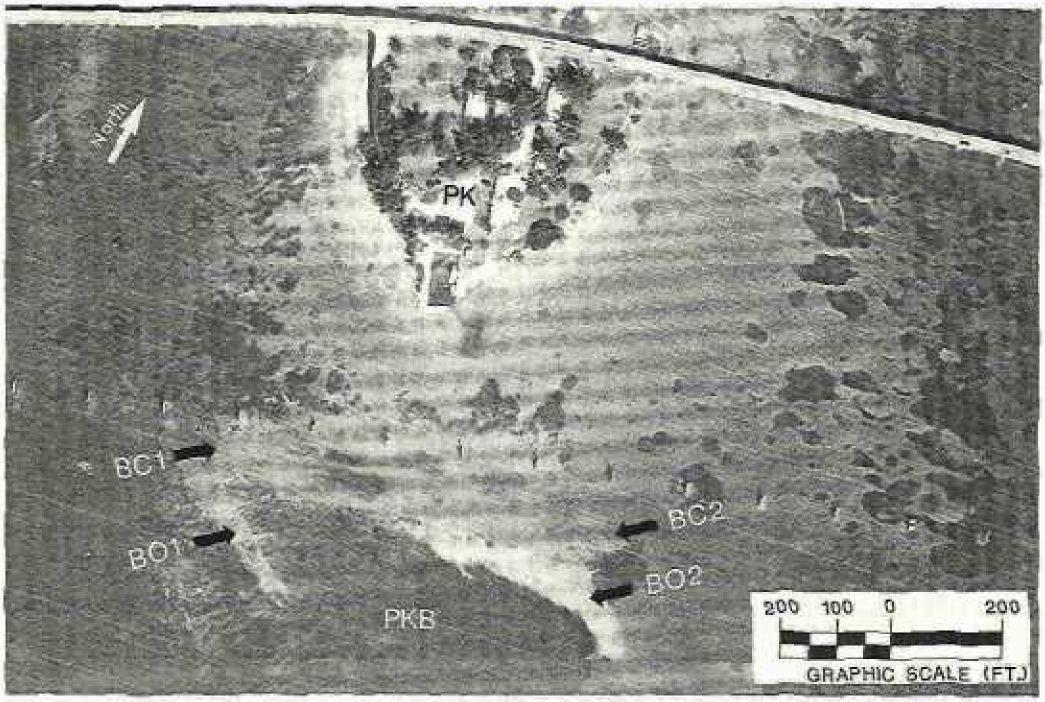


Figure 45. Vertical aerial photograph taken February 25, 1981, *showing* Pigeon Key (PK) and the adjacent new alignment for the 7-Mile Bridge. *Pilings can be seen installed in the* new alignment and in the excavated barge access canal (BC1-BC2) across the shallow Pigeon Key Banks (PKB). Two blowouts of sand are spread over the adjacent turtle grass meadow (BO1 and BO2). The old 7-Mile Bridge is at the top of the photograph. Site F (Figure 42) is shown here.

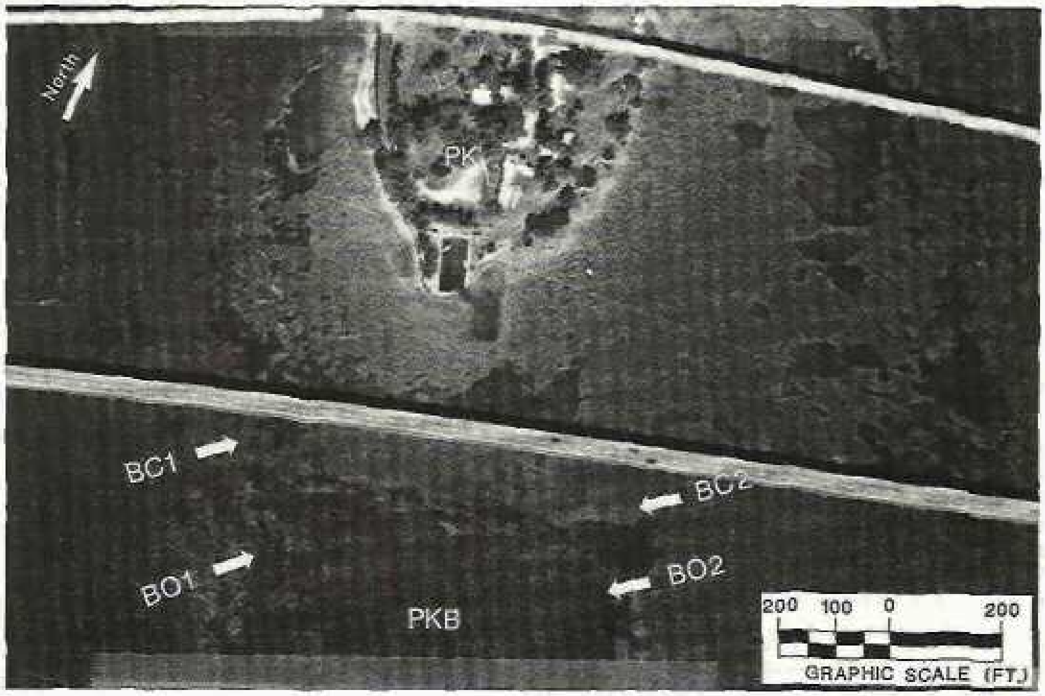


Figure 46. Vertical aerial photograph taken February 12, 1991, of the same area shown above. The new 7-Mile Bridge can be seen in its completed form. The excavated barge access channel is still very evident (BC1-BC2). The two sand blowouts are completely revegetated (BO1 and BO2).

General Observations

Observations to date indicate these primary factors (in probable order of importance) limited the success of these seagrass plantings in the Keys:

1. lack of suitable sediment thickness to support root growth (e.g., Site 18, Seven Mile Bridge);
2. bioturbation by burrowing animals such as *Callianassa* and surface feeders such as *Limulus* (e.g., Site 24, Craig Key and also noted by Fonseca 1994);
3. water depth and suspended sediment in unvegetated excavations (e.g., Site 6, Park Channel);
4. human disturbance due to foot traffic (e.g., Site 25, Indian Key Channel) or boat traffic (e.g., Sites 16 and 17, Seven Mile Bridge).

Some of these problems were anticipated, but were essentially experimentally tested. Derrenbacker and Lewis (1983) were able to achieve some *H. wrightii* survival and growth on rocky substrate in a very low current area in north Key Largo, but apparently this is not possible in higher current areas. Williams (1990) has also documented the role of rhizophytic algae in initially establishing a nutrient supply for later successional stages in natural seagrass restoration. Fertilization may therefore play a role not tested in the Keys to date. However, Fonseca (1994) states that "the influence of fertilizer on plantings has not been predictable" (p. 12).

III. PROP-DREDGED SITES

Mangrove Systems, Inc. (1985) tallied a total of 65.8 acres of damaged seagrass associated directly with the Keys Bridge Replacement Program. Of this amount, 18.18 acres at nine sites were the result of propeller cuts or wash in shallow water which either excavated or buried seagrass meadows. This total did not include the 27.09 acres of prop dredging north of the Niles Channel Bridge that was the subject of a lengthy lawsuit that has yet to be resolved (*U.S.* v. *MCC*), although the marine contractor was adjudged liable for the damage. Adding this area brings the total impact to 93.33 acres, of which 45.71 acres or 48.9% was the result of prop damage at ten sites (Table 4).

A typical example of this kind of damage is shown in Figure 47 which depicts numerous overlapping prop cuts in a shallow *Thalassia* meadow adjacent to the new span of the 7-Mile Bridge. The same area is shown in Figure 48 in 1991. None of the damage is visible. The site was inspected in June 1993; no identifiable prop scars were visible. The mixture of seagrasses includes *Syringodium* as well as *Thalassia*, whereas the adjacent control area is monotypic *Thalassia*.

Five additional sites totaling 41.05 acres of prop damage were examined from the air and on the water. All but one showed essentially 100% recovery from the historic damage. The one site with only partial recovery is the Niles Channel site where 23.22 acres of the total 27.53 acres of damage have naturally revegetated, although substrate discontinuities still exist. Most of this is in the area of Site 2 which was composed of numerous individual prop scars extending for several miles north of Site 1, the major area of concentrated damage (Figure 49). Figure 50 shows Site 1 in 1993 and the central prop-scarred channel across the shallow bank is still quite visible.

Figures 47-48

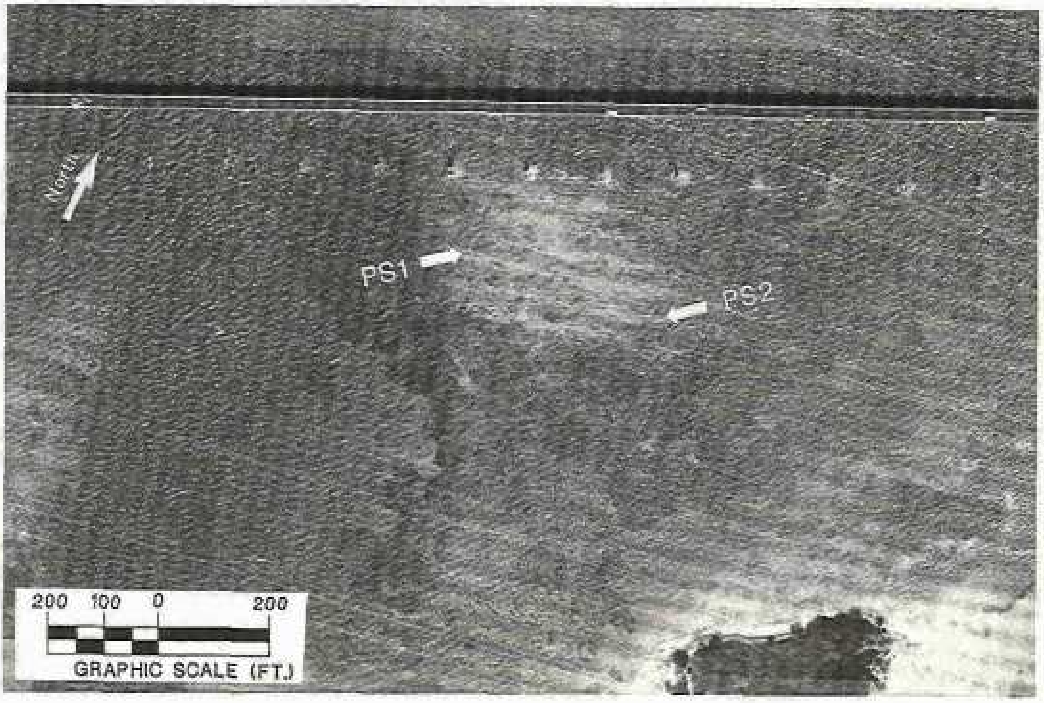


Figure 47. Vertical aerial photograph of the 7-Mile Bridge taken February 25, 1981. A 2.21-acre prop scar area is shown within the arrows (PS1-PS2). This is site B (Figure 4?).

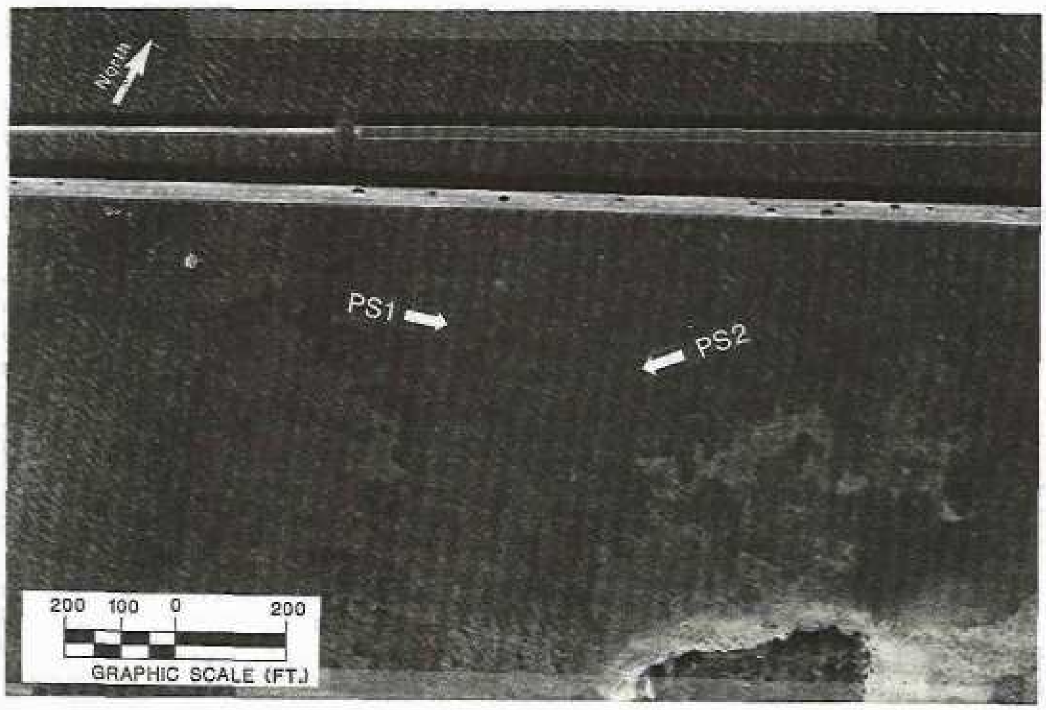


Figure 48. Vertical aerial photograph of the same site as above, taken February 12, 1991. The location of the previous prop scar is indicated by PS1-PS2 as above.

Figure 49. Niles Channel Site 1, 1983.

Figure 50. Niles Channel Site 1, 1993.

The right-hand column in Table 8 itemizes all the 1993 observations and includes 62.2 acres of new seagrass observed in Boca Chica Lagoon (Section IV). A total of 134.19 acres of restored seagrass now exists, exceeding the original impact by 40.86 acres.

IV. TIDAL CIRCULATION RESTORATION AND CULVERT INSTALLATION

The lagoon at Bahia Honda has been surveyed on several occasions to obtain basic water quality data at different tide levels, to observe fish and wildlife use, and to map the current extent of mangroves. Data gathered allows evaluation of on-site mangrove density, percent cover, and height by species. On-site photography has been repeated to illustrate changes in conditions as a result of excavation of the swale.

Several inspections at different tide stages have been made of the three culvert systems (C-2, C-3 and C-4) installed under Boca Chica Road, and at the two culvert sets installed under the old Lower Sugarloaf Road. Basic water quality monitoring has been conducted here and at nearby sites. Observations of fish and wildlife use, circulation patterns, erosion and accretion, and natural recruitment of mangroves have been made. Photography has been used to document 1981 and 1993 conditions at Boca Chica.

Bahia Honda Key

Encompassing an area of approximately 314 acres, Bahia Honda Key is one of the least developed land masses in the Florida Keys and remains relatively pristine. Public access is largely restricted to the Atlantic beachfront and campsites on the western end of the island. Isolated ponds, a former borrow pit, and a small mangrove lagoon (the study site) are on the western bay-side of Bahia Honda. Two large, tidally flushed mangrove lagoons are on the eastern end of the island, divided by the fill causeway for U.S. 1. The lagoon on the northern side of the highway is flushed by a tidal creek system while the lagoon on the south side is flushed by three 36-inch diameter concrete culverts.

The study site is a small (6.6 acre) shallow, bay-side lagoon at the western end of Bahia Honda Key. It is bordered on the south by U.S. 1, on the west by a former Monroe County landfill, and to the north by a mangrove ridge (Figures 51-52). Limited tidal exchange occasionally occurred during high spring tides through a partially occluded existing culvert in the northwest corner of the lagoon. Storm surges generated by northerly winds sometimes breached the mangrove ridge in areas of lower elevation, but exchange was minimal. No tidal exchange was ever observed through a second existing culvert in the lagoon's southwestern corner.

Although undeveloped compared with many areas in the Keys, modifications of the natural topography and hydrology at Bahia Honda have occurred, confusing interpretation of its geomorphic evolution. Man's impact notwithstanding, knowledge of the recent developmental history, together with available aerial photography permits some speculation about how the island's lagoonal systems have changed over time.

The most significant impact to the ecosystem was the dredging and filling accompanying the construction of the railroad causeway. This bisected the large central lagoon and restricted tidal circulation at the western end of the key, resulting in the formation of several isolated ponds and a small lagoon (the study site). Most subsequent development

Figures 51-52.

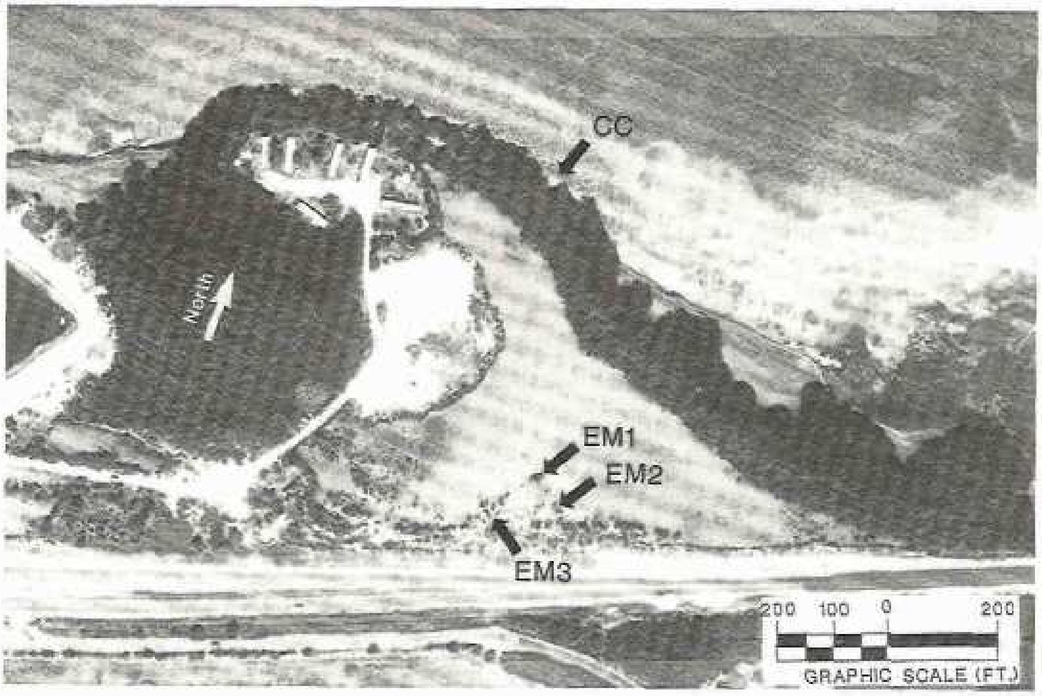


Figure 51. Vertical aerial photograph of Bahia Honda Lagoon taken February 25, 1981. CC indicates the location of the circulation cut to be made. EM1, EM2 and EM3 indicate existing clumps of mangroves (also located for reference below).

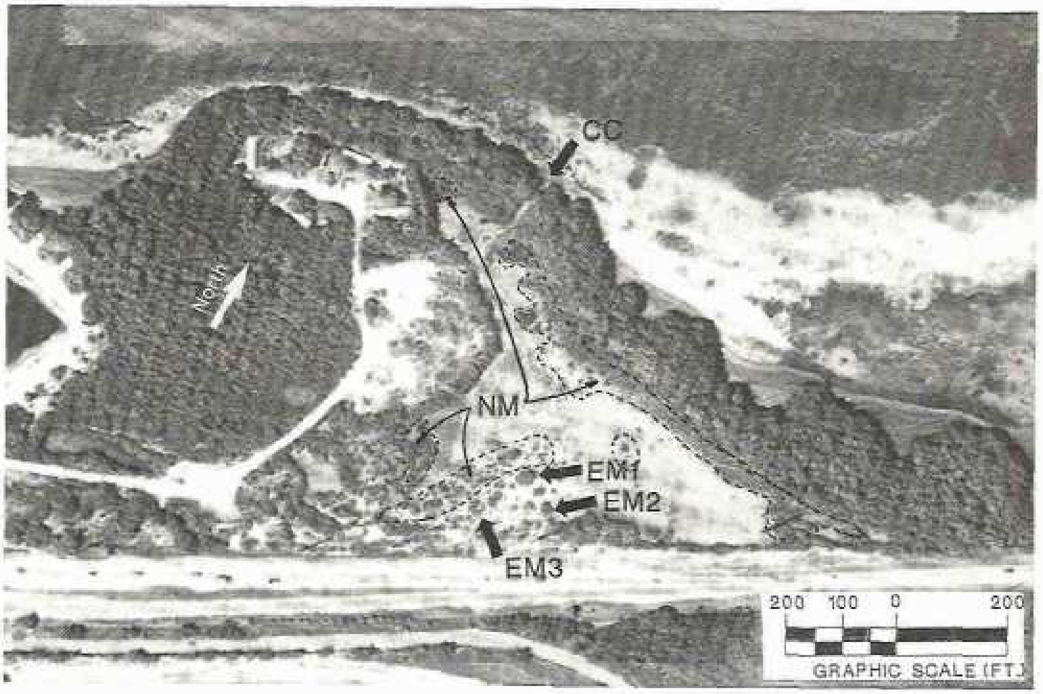


Figure 52. Vertical aerial photograph of Bahia Honda Lagoon taken February 12, 1991. CC indicates the location of the circulation cut made in March 1981. NM and dotted lines indicate the location of areas of natural mangrove recolonization, 1.35 acres (compare with above).

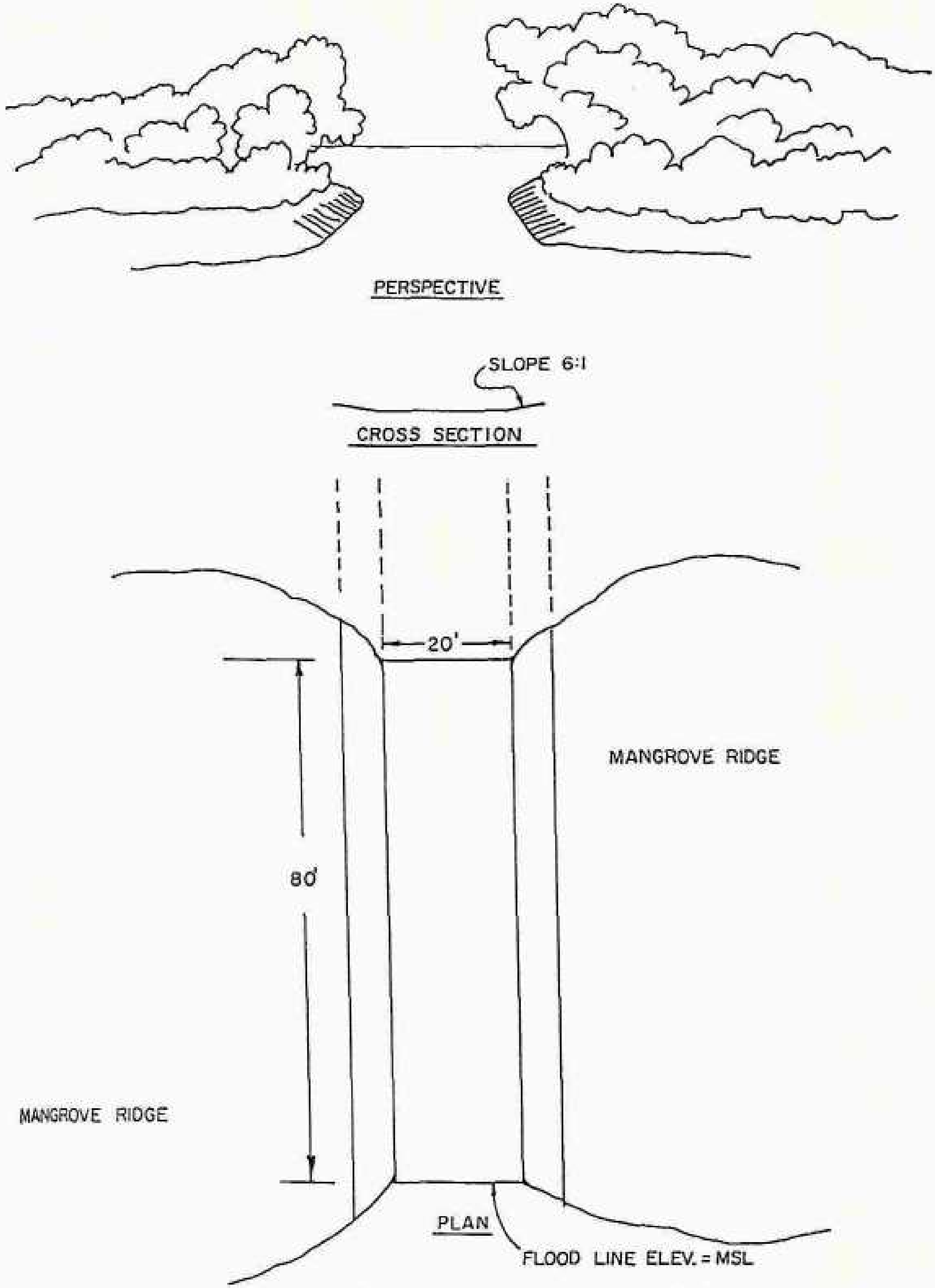
has occurred on the island's western end in the vicinity of the study site. Use of the area as a county landfill and excavation of the borrow pit only served to worsen tidal circulation to the study area. This was ameliorated somewhat by installation of two culverts to the lagoon when the Department of Natural Resources covered the landfill to create a residence area for park rangers. The culverts were apparently too small or too few to be effective as they eventually became blocked with sediment and debris, again reducing circulation.

In November 1980, R. S. Futch Co. was awarded a contract (SP No. 90000-3522) to excavate a swale through the mangrove ridge at the study site and to install an 18-inch diameter corrugated aluminum culvert between the borrow pit and a small pond (Figures 51-52). Construction drawings for the swale are shown in Figure 53. Work began on March 30, 1981, and was completed by April 2, 1981. To minimize the construction impact to the study area, wooden mats were laid across the lagoon from the landfill area to the ridge so that heavy equipment could gain access to the job site. Materials removed from the swale site were disposed of on the landfill, burned by the park staff, and subsequently graded to the natural contours of the area.

An extensive pre- and post-construction monitoring program was begun two years prior to construction of the opening and continued for 18 months after construction (September 1982) (Jordan 1986). Parameters studied included tidal circulation, topography, sediment grain size, water quality, benthic infauna, and fish. The major conclusions of the study are summarized here:

1. The lagoon's hydrology changed from a gradual seasonal decline in water level between December and March, as evaporation exceeded rainfall, and major increases with rainfall in the summer, to a typical daily tidal regime except when natural blockages of the excavated opening occurred.
2. While water temperature, pH and dissolved oxygen showed little change after opening, salinity moderated significantly (Figure 54), eliminating hypersaline conditions that routinely stressed the lagoon's plants and animals.
3. The predominant green algae occurring in the lagoon prior to opening quickly disappeared, to be replaced by *Batophora oerstedi.*
4. Polychaetes were the dominant infaunal group throughout the study. Restoration of tidal circulation did not result in a large qualitative or quantitative change in the benthic community (Figure 55), probably due to the intertidal nature of the lagoon after opening, which produces seasonal drying events.
5. Fish populations prior to opening consisted of only two euryhaline species, *Cyprinodon variegatus* and *Fundulus grandis*. After opening, fish abundance increased by several orders of magnitude and five additional species were present.

For this study, several site visits were made, including one in July 1993. Figures 56 and 57 show the excavated opening in 1981 and twelve years later. Field measurements compared to Figure 53 indicate that that the opening has remained remarkable stable, losing less than 20% of its area in twelve years. Figures 58 and 59 show the significant colonization by and rapid growth (to 3 m tall) of volunteer red mangroves which did not occur inside the lagoon prior to opening (see also Figures 60-61). Numerous fish and wildlife species were observed within the lagoon including reddish egrets, roseate



Construction Drawing of Swale at Bahia Honda

Figure 53.

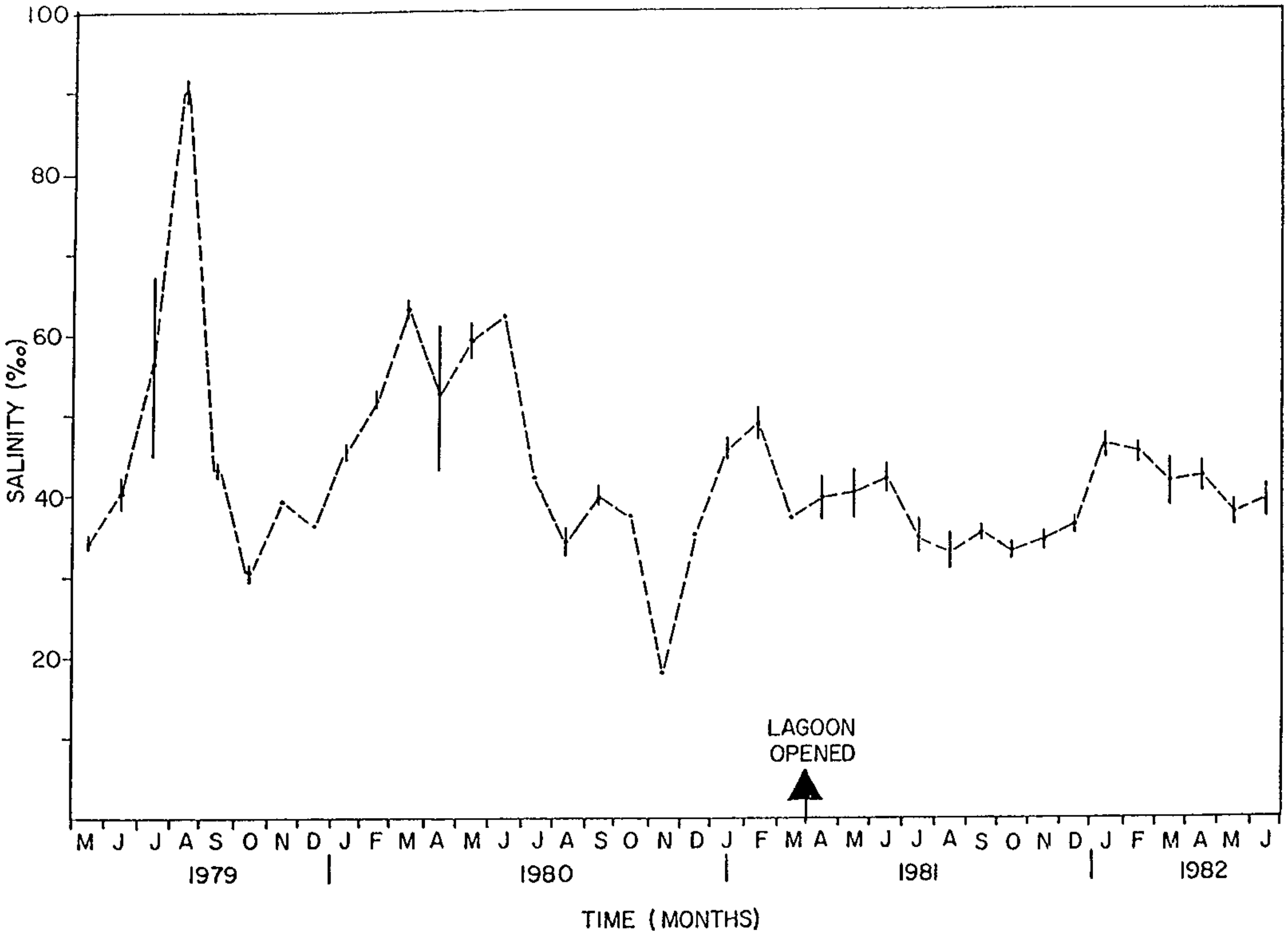
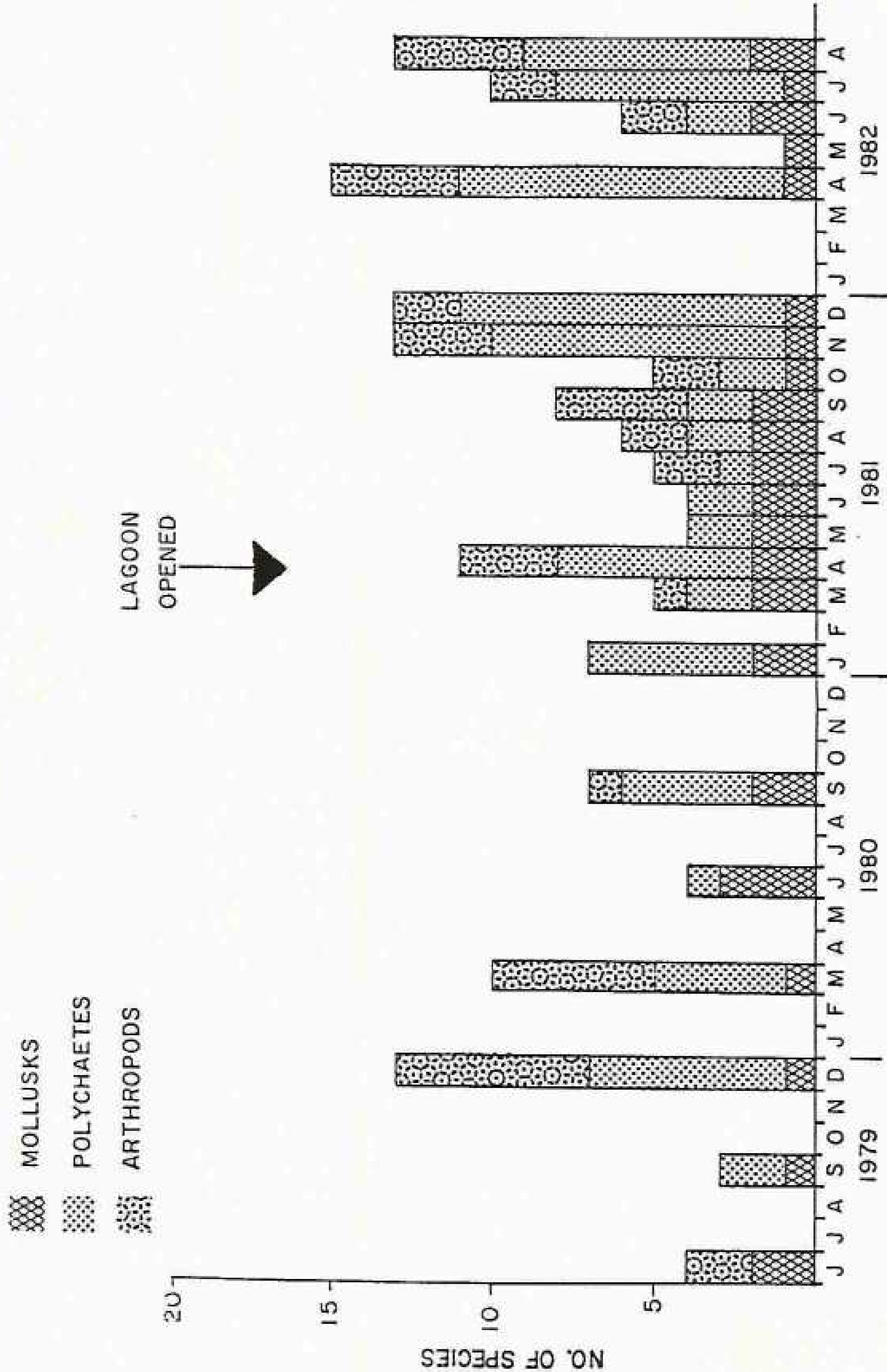


Figure 54.

Temporal Variations in Salinity at Station BH-15

Figure 55.



Number of Species of Mollusks, Polychaetes and Arthropods at Station BHH-40

Figure 56. Bahia Honda Lagoon, circulation cut, 4/81.

Figure 57. Bahia Honda Lagoon, circulation cut, 7/93.

Figure 58. Bahia Honda Lagoon, no red mangroves on inside, 4/81.

Figure 59. Bahia Honda Lagoon, red mangroves now on inside, 7/93.

Figure 60. Bahia Honda Lagoon, view from U.S. 1, 5/85.

Figure 61. Bahia Honda Lagoon, view from U.S. 1, 7/93.

Figure 62. Roseate Spoonbill in Bahia Honda Lagoon, 1993.

Figure 63. Mangroves in Bahia Honda Lagoon, 1993.

spoonbills (Figure 63), and mangrove water snakes (*Nerodia fasciata compressicauda*). Fish were very numerous in the area surrounding the excavated entrance and were predominantly small forage fish dominated by *C. variegatus*, *F. grandis*, *F. similis*, and *Lucania parva*.

Boca Chica Lagoon System

This system of shallow (0.5-1.0 m deep) semi-impounded, irregularly shaped, interior lagoons extends nearly two miles east-west and about 0.6 mile north-south (Figure 19). For many years prior to FDOT's culvert placement in early 1982, the only tidal connections were to the west through about a half mile of mangrove forest and shallow creeks, and through an existing set of culverts to the Atlantic near the east end. There is no connection between the two large ponds during extreme low water periods of late winter; a natural berm and shallow creek separate the ponds. This system was believed to be subject to seasonal hypersalinity as are other Keys "salt ponds". This condition is confirmed by a review of 1981 and earlier vertical and oblique aerial photographs. Little submerged vegetation existed, particularly in the west part of the system, and black mangroves were the only mangroves on the shorelines.

In early 1982 the FDOT placed three sets of 4-barrel 42" x 29" aluminum arch pipe culverts at an invert elevation of -1.2' MSL about one-half mile apart under Old Boca Chica Road. These connected the south edge of the lagoons at three locations to the Atlantic Ocean. Paired riprap groins of various lengths were constructed out from the culvert headwalls protecting a channel/sump area dredged to about -4' MSL. The headwalls are all set at +2.0' MSL and are awash during spring high tides.

The physical condition of the culverts appears good except for minor erosion around some headwalls. The channel/sump is being maintained at each by the strong currents that flow through the culverts on most tides, especially spring tides. However, observations revealed that little flow occurs during the lowest tides due to shallow conditions including considerable exposed mud and shoalgrass banks. Red mangroves are now colonizing the interior areas including the mud banks, providing diversity of habitat by lining the lagoons near the culverts. But red mangroves may also represent a threat to the future of these areas by gradually closing off flow-ways, including the narrow, shallow creeks that still flow during the lowest tides. The pre-existing culvert set to the east was maintained by excavation at about the same time the FDOT culvert sets were placed. It is again in need of maintenance due to redistribution of material off both ends of the culvert.

An inspection by canoe in May 1993 (spring dry season) of the large interior pond to the west revealed that moderate to dense shoal grass (*Halodule wrightii*) extended throughout much of the area with the exception of the northeast regions where it is limited to a few small shoreline patches. A total of 65.2 acres of new seagrass area was mapped (Table 8). A review of 1981 aerials revealed that little submerged vegetation existed in this lagoon, probably a result of frequent hypersalinity and possible seasonally high temperatures. Salinities during this May inspection were 55 ppt in the upper (north) reaches of the lagoon, gradually decreasing to 40-42 ppt near the two sets of culverts which connect this lagoon to the Atlantic. Temperatures ranged from 79° to 85° F with the higher temperatures near the culverts. Similarly, on September 20, 1993, during the late summer rainy and high water period, salinities were 44 ppt in the upper reaches of the lagoon and 35 ppt near the two culvert sets. These measurements, taken during high and low water periods, indicate that severe hypersalinity may no longer be a limitation to either seagrass (especially *Halodule*) or red mangroves which are now common in the south part of the system.

Boca Chica Culvert C-2

This culvert site, the easternmost of the three FDOT Boca Chica culverts (Figures 64-65), was inspected on July 19 (high water), and September 18 and September 20 (low water), 1993. The culverts connect a relatively small, shallow (+0.5' to -1.0' MSL) pond to the Atlantic. Separating this pond from the large lagoon to the north is a natural, low, storm-generated sand and shell berm that forms the south edge of the lagoon. This berm (about 80 m from the culvert) achieves only about +3' MSL elevation and 15-25' width but is large enough to form a barrier between the pond flushed by the culvert and the lagoon. Berm vegetation includes buttonwood, bay cedar, black mangroves, saltgrass, sea ox-eye, glasswort, and scattered red mangroves. Tidal flow from the culvert moves east and west on the south side of this berm, apparently overtopping the berm only in a few locations and only during the very highest tides.

Depths in the dredged areas in front of the culvert remain at about -3.0' to -4.0' MSL as a result of strong tidal flow but about 40' to the south depths are shallow in unvegetated mud to about -0.5' MSL. Naturally occurring rock is shallow north of the culvert compounding the process of natural filling.

Salinity measurements confirmed that the berm acts as a barrier to the mixing of lagoon waters to the north with the pond and creeks influenced by the culvert. During high water in July, waters north of the berm ranged from 48-52 ppt while those near the culvert a short distance away were 38 ppt. In September, during lower tides, salinity in the large lagoon was 43 ppt while waters at the culvert (falling tide) were measured at 35 ppt.

Natural recruitment and establishment of red mangroves has been high, with a considerable amount of the interior pond now colonized. Immediately east and west of the culvert are dense stands of red mangroves 4-5 m tall that cover mud banks previously unvegetated or vegetated with scattered black mangroves. Along the rest of the lagoon edge, red mangroves 1-3 m tall now form a nearly solid fringe, and scattered red seedlings and shrubs are taking root in the pond. Landward of this new fringe are mixed red and black mangroves, a result of reds colonizing areas of pre-existing, scattered black mangroves. Red mangroves follow the zones of tidal current circulation (deepest areas) that occur as a result of the culverts; the relative number of red to black mangroves decreases as one moves east and west away from the culvert. Based on a review of low-level 35 mm aerial photographs taken at the time of culvert installation, the existence of these red mangroves in the interior is a direct result of culvert placement; therefore, their age is a maximum of about 11.5 years (as of late 1993) and they cover an area of 6.45 acres (Table 3).

A comparison of 1981 to 1991 aerials also shows that the extent of red mangroves along the Atlantic shoreline of Boca Chica has increased. This is also true of the ocean side of

Figures 64-65.

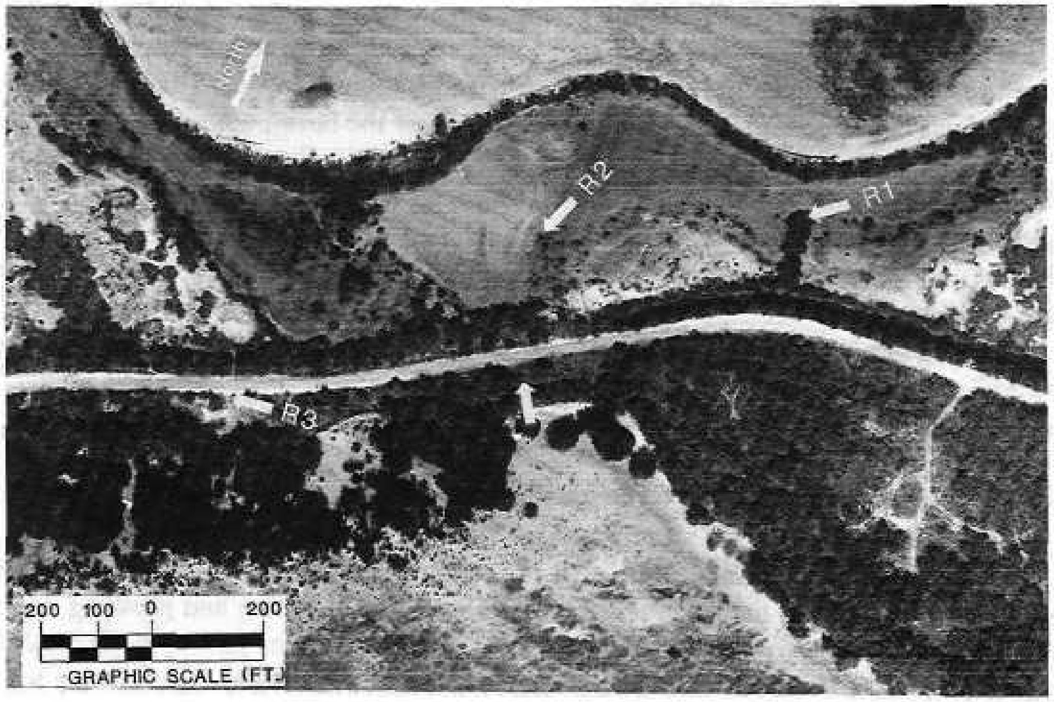


Figure 64. Vertical aerial photograph taken February 25, 1981, of the proposed location (at arrow) of culvert C2 into Boca Chica Lagoon. Reference locations are marked R1, R2 and R3.

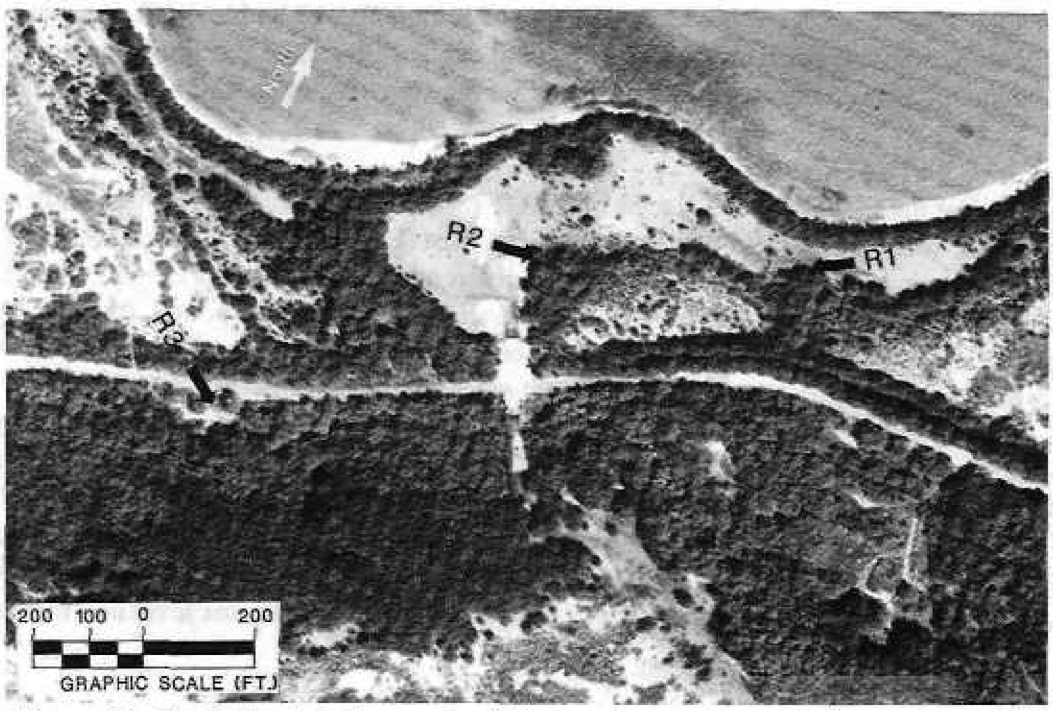


Figure 65. Vertical aerial photograph of the location of culvert C2 (in center) with the same three reference points marked as above. Photographed February 17, 1991.

culvert C-2 where the extent of red mangroves has expanded considerably and now threatens to block the shallow, mostly intertidal, flow-ways to the culvert.

Halodule now occurs in the interior pond but did not appear in 1981 or 1982 aerials of the site. Probably due to shallowness, shoal grass occurs only in a few small patches near the culvert, but is moderately dense in slightly deeper water (about -0.5' to -1.0' MSL) to the east. Shoal grass was not observed in the large lagoon north of the berm, where only the green algae *Batophora* and *Acetabularia* occur at depths of about -0.5' to -2.5' MSL.

Fish and wildlife observed at or near the culvert included snook (18"-24"), needlefish, juvenile and adult mangrove snapper, numerous sheepshead killifish, *Fundulus* sp., mojarras, and fingerling mullet. Fiddler crabs were common in intertidal areas near the culvert. Birds observed during site inspections were white ibis, tricolor heron, green-backed heron, reddish egret, kingfisher, clapper rail, willet, and unidentified shorebirds. Feeding wading and shorebirds are common here during low water levels.

The berm just north of culvert C-2 is documented to be a barrier to tidal flow desired for the large lagoon to the north. It was anticipated by FDOT and others that the berm would eventually be channelized by tidal flow but this has not happened. Tidal influence is now limited to the area south of the berm and the area appears to be filling and growing in with red mangroves. Depths already appear to be too shallow for seagrasses just north of the culvert and mangroves are beginning to close off the ocean side of the culvert, possibly due to reduced flows during low water periods.

It is recommended that consideration be given to excavating or blasting two breaks in the berm a minimum of 5 m wide to the depth of the natural rock (about -0.5' MSL). The two locations recommended are approximately due north of the culvert and about 80 m to the east of this site. Also, because of the encroachment of red mangrove on the ocean side, root and possible tree removal out from the culvert should occur at the same time of excavation of the berm cuts in order to maximize tidal currents that may serve to maintain these openings.

Boca Chica Culvert C-3

The central of the three culverts placed by FDOT provides tidal flushing to the southeast corner of the westernmost large lagoon of Boca Chica (Figures 66-67). What was once a shallow, open pond immediately north of the culvert site now has the appearance of a tidal creek (-1.5' to +0.5' MSL) with red mangroves encroaching into the "pond", framing the creek sides. During low water periods, flow-ways north of the culvert are limited to two small tidal creeks through the mud and seagrass flats that extend to the northwest.

This site was inspected on May 25 (high water), and September 18 and 20 (lower water), 1993, and January 15, 1994 (low water). On September 20, during an oceanside low tide, the water appeared perched 0.5-1.0' to the north of the culvert, a result of water levels in the ocean dropping faster than water could drain from the interior. Late September and early October are high water periods in the Keys, as a result of high mean sea level and rainfall.

Figures 66-67.

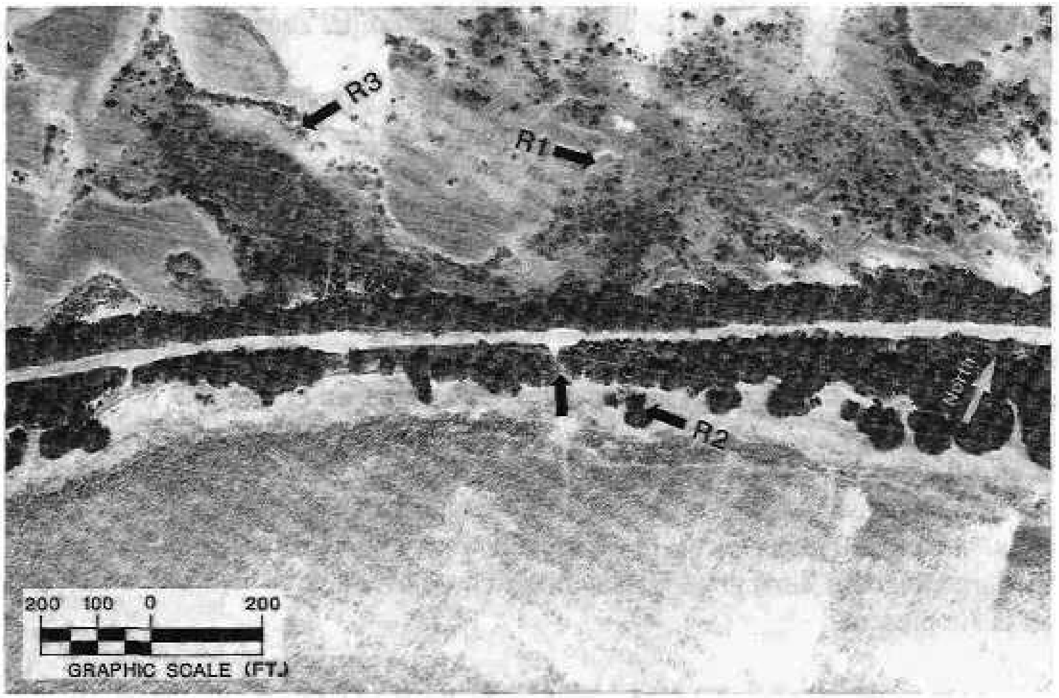


Figure 66. Vertical aerial photograph taken February 25, 1981, of the proposed location (at arrow) of culvert C3 into Boca Chica Lagoon. Reference locations are marked R1, R2 and R3.

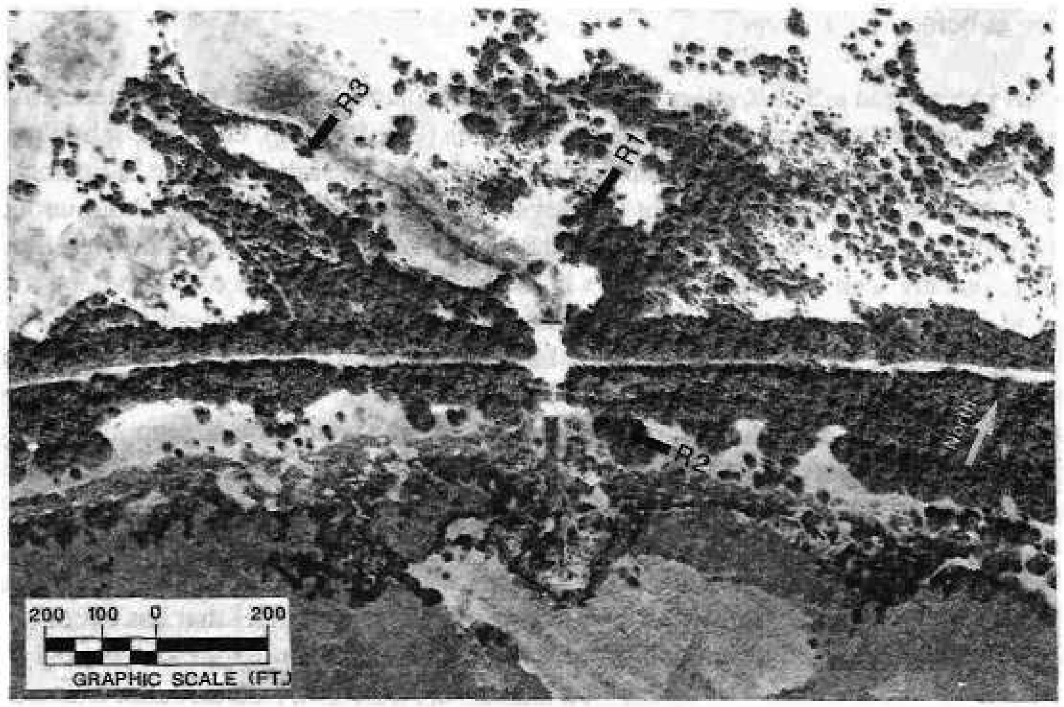


Figure 67. Vertical aerial photograph of the location of culvert C3 taken February 17, 1991. The same three reference points are marked as above.

Depths in the excavated areas at each end of the culvert are about -4.0' to -6.0' MSL in places; tidal currents are frequently strong. The Atlantic side of the culvert remains open water but depths are naturally shallow offshore, and at extreme low tides exchange is limited to a few shallow flow-ways eroded through the broad shoreline intertidal zone.

As at the easternmost culvert (C-2), a review of aerial photographs reveals that only black mangroves were present inside the lagoon at the time of culvert placement. Natural recruitment of red mangroves since 1982 has resulted in substantial areas now densely vegetated with reds to 4.0 m tall. Fringing areas are about 100% red mangroves with a mixture of red and black mangroves in landward zones where newly recruited reds are mixing with pre-existing black mangroves. Based on representative quadrats east of the culvert, the density of 8.5 red mangroves (to 4.0 m tall) was per square meter, 3 red mangrove seedlings (to 0.5 m tall) per square meter, and 4.5 black mangrove seedlings (to 0.5 m tall) per square meter. A total area of 4.58 acres of new mangrove was mapped (Table 3).

Seagrasses did not occur in the adjacent interior lagoon at the time of culvert placement. *Halodule* now covers about 70% of the shallow area north of the culvert not vegetated with mangroves. About 120 m northwest of the culvert where the narrow channelized area now meets the larger lagoon, shoal grass is moderately dense over a large area and small patches of turtle grass are present.

The salinity survey during high water in May 1993 (dry season) revealed salinities around 40 ppt at and near the culvert (both sides) increasing to about 42-44 ppt inside the lagoon a distance of 300 m, and a range of 47-55 ppt in the central and north part of the lagoon. Water temperatures ranged from 79-85° F with the warmest waters in and near the ocean. The extent of shoal grass and the colonization of much of the shoreline in this lagoon by red mangroves (particularly in the south) indicate that hypersalinity may not be as limiting an influence as before in this area.

Numerous sheepshead killifish, silver jenny, yellowfin mojarra, toadfish, mullet, needlefish, numerous mangrove snapper, needlefish, 10 barracuda (24-30" long), clupeids, schoolmaster snapper, and sergeant major were observed at culvert C-3. The latter two are indicators of good tidal flushing and water quality in the Keys. Invertebrates noted included numerous green hermit crabs, horseshoe crabs, fiddler crabs, crown conchs, and upside-down jellyfish. Birds were usually seen feeding in shallows in the interior as well as on offshore flats. Great blue heron, little blue heron, tricolor heron (common in January), green-backed heron, yellow-crowned night heron, reddish egret, brown pelican, red-winged blackbird, gray kingbird, kingfisher, and prairie warbler were noted. An adult bald eagle was seen cruising low along the mangrove edge on the outside of the culvert. A roseate spoonbill was seen just offshore in January, with a large mixed flock of white ibis, snowy egret, great white heron, shorebirds, little blue heron, tricolor heron and reddish egret.

Although virtually all of the mangroves north of the culvert flood during spring high tides, much of the current flow is directed to the northwest along the channel that has become established. As red mangroves grow into more of the intertidal zone, this channel may become constricted. Influence of this culvert is already limited as a result of the distance to the main lagoon to the northwest. Restrictions in flushing in this small channel could result in limiting conditions again becoming established in the lagoon. Shallowing to the north as a result of the accumulation of fine sediment moving in the culvert area from the ocean could eventually warrant hydraulic dredging. The "pump and dump" method (hydraulic pump to a tanker truck) could minimize disturbance while excavating a deeper flow-way to the northwest.

Boca Chica Culvert C-4

The westernmost of the three FDOT culverts is located at the end of a shallow arm extending southwest from the large lagoon (Figures 19-21). Shallow water north of the culvert and to the east restricts flushing during lower tides. Like C-3, the influence of this culvert is somewhat reduced by the distance to the main part of the lagoon. The ocean side of the culvert fronts on open water with intertidal seagrass flats forming much of the offshore area. Tidal currents from the culverts have eroded narrow shallow channels through the offshore flats. This site was inspected on May 25 (high water), September 18 and 20, 1993 and January 15, 1994 (low water).

Due to strong currents and erosion, depths to about -8' to -10' exist just north of the culvert, well below the excavated depths. There are shallow unstable mudbanks just beyond the inside dredged area, probably a result of eroded material and fine sediment entering the interior from the ocean during storm events. Depths in the interior are shallow with deepest areas only about -1.0' MSL. Inspections during low water conditions revealed three small flow-ways inside through exposed mud banks that included minor shoal grass.

As a mitigation requirement for destruction of mangrove wetlands on the Florida Keys Bridge Project, FDOT agreed to plant 80,000 red mangrove propagules in the newly connected interior lagoon just inside and east and west of culvert C-4. Planting was performed by prison labor crews with oversight by FDOT and was completed in early August 1983, about 18 months after the culverts were installed. Some control plot stakes set east of the culvert were located in 1993, but the precise location of control plots could not be determined, partly because of the density of the 4-6 m tall red mangroves that cover the area. Ground photographs of the control plots taken in May 1985 show healthy red mangrove seedlings from about 0.4 to 0.8 m tall, some with initial prop roots. The planted area immediately west of C-4 now contains 4.5-5.5 m tall red mangroves with some pioneering black mangroves (Fiugres 21 and 22). Representative 4 m^2 quadrats located in the dense monoculture of planted mangroves to the east showed densities of red mangrove trees (1.5 to 6.0 m, most 4.0-6.0 m tall) to average $3/m^2$ and seedlings (0.3-0.5 m tall) to average $1.1/m^2$. Pioneering mangroves on the edge of this monoculture averaged 7.8 red mangrove trees per square meter (1.0-1.6 m tall), 6.0 small reds (0.3-1.0 m) per square meter, and 4.5 small black mangroves (0.3-1.0 m) per square meter.

Although pioneering mangroves are common in the interior here, the planting of mangroves resulted in considerably larger mangrove stands and larger trees than at culverts C-2 and C-3. As at C-2 and C-3, pioneering red mangroves now line the flow-ways to the interior and have filled in areas previously vegetated only by black mangroves. A substantial area of previously unvegetated mud flats inside C-4 is now vegetated with red mangroves (95%), with black mangroves (5%) on higher spots, along with some *Batis*. As a result of the shallowness of the interior area, and a large seed source, red mangroves ranging from newly sprouted propagules to 1 m tall or more are scattered throughout, indicating that the process of filling and growing in is proceeding. Red mangroves from 1.0 to 2.5 m tall line the edges of the lagoon for about 400 m to the east.

Probably as a result of hypersalinity, no seagrasses were present in this interior area in 1981 or 1982. About 75% of the open shallow channel and small interior lagoon to the east is now vegetated with shoal grass and a few small areas of turtle grass. Shallow depths are probably a limitation to turtle grass in these small interior lagoons. The green alga *Batophora* is the only other common macrophyte.

Dry season salinities during high tide in May 1993 were 40-42 ppt near the culverts and 44-55 ppt in the interior lagoon, increasing away from the culvert.

Mullet, silver jenny, yellowfin mojarra, numerous mangrove snapper, barracuda, needlefish, mosquitofish, and numerous sheepshead killifish were observed at this culvert. Schools of killifish, mosquitofish and mojarras are concentrated during low tides, providing good feeding areas for wading birds. Invertebrates seen included blue crab, hermit crabs, and upside-down jellyfish. Birds observed include reddish egret (white and red phases), tricolor heron, little blue heron, great white heron, great blue heron, snowy egret, mangrove cuckoo, brown pelican, kingfisher, osprey, bald eagle, red-winged blackbird and red-breasted merganser.

At culvert C-3 there is a likelihood that the interior of this area will continue to fill and grow in as a result of fine sediment transported in through the culverts and settling in the quiet zones. Shallow and exposed areas during extreme low tides now limit flushing. Maintaining a channel to the northeast will probably be desirable at some point in the future. Routine monitoring of conditions here (and at other culverts) will be necessary to properly assess the need to maintain tidal flushing and prevent limiting hypersalinity from again occurring in the interior lagoons.

V. BRIDGE SLOPE REVEGETATION

In the late 1970s and early 1980s there was considerable agency debate about the most practical method of stabilizing the newly constructed and filled bridge approach slopes. This review concerns the upland portion of the slope, from the edge of pavement downslope to the beginning of the developing wetland zone. Environmental concerns included water quality degradation during rainstorm events from silt and fine material washed from the exposed, crushed limestone rock used for fill material. Siltation of nearby seagrass beds was also a concern. Runoff was documented by the DER and COE but the significance of runoff of this material to the adjacent marine system was subject to varying opinions. Much of the runoff was captured by the riprap and mangrove swales constructed at the bottom of the new slopes. Further complicating the issue was the use of some slopes for summer nesting by the Least Tern (*Sterna antillarum*), a state-listed species.

Originally, extensive sodding of the slopes was planned but eventually the projected high expense of this work led FDOT and the agencies to explore alternative methods that could be used to accomplish the agreed-upon purpose, "... accelerate the natural revegetation process by 2-3 years" (J. C. Kraft, FDOT, letter to S. Fox, DER, 7/21/81). A sod strip placed at the edge of pavement on many approaches was successful at protecting the pavement/fill edge and accelerating the revegetation process at the very top of the slope. However, vehicles leaving the pavement often destroyed this planted material.

In July 1981 the FDOT constructed experimental plots on the slope at each end of the Lower Sugarloaf Channel bridge (Gulf side) to test the potential of a "mower clipping" technique to spread cut mulch and seed from donor grassy areas elsewhere in the Keys. A grid was created for monitoring purposes and different treatments, including hydromulching, were used. Donor sites were inventoried prior to mowing and collection of the mulch. Fourteen bags of mulch were spread at Lower Sugarloaf Channel (Zeigler, FDOT, 7/24/81 memo). Germination of some seeds within the plots was reported by Zeigler in August 1981. In December 1981, David Crewz, a botanist with the Florida DNR, reported a 20-fold increase in plants since August, mostly grasses and composites. Crewz also noted considerable variation among plots and a number of volunteers from elsewhere, and recommended further assessment based on potential for use as stabilization.

In April 1982, DER-Marathon reported that this experimental technique appeared to work well and noted that all of the plots were "... standing out as green strips on a white background" (Bishof, DER, letter to G. Rivers, FDOT, 4/27/82). If the success could be confirmed through further evaluation by a botanist, DER recommended that the technique be used to implement revegetation of all slopes as soon as possible. DOT's evaluation of the experiment in May 1982 showed that although "... vegetation in the plots is more prolific than surrounding areas, areas of this and other slopes are exhibiting denser natural vegetation" and "... assessment of the value of this vegetation in holding fines is that they are almost completely ineffective" (Evink, DOT, 5/18/82 memo).

DER later deemed the Lower Sugarloaf Channel experiment successful based on the revegetation process being accelerated. They directed DOT to spread mowed and bagged clippings in spaced 2'-wide strips, parallel to the highway, on the unvegetated portions of slopes where construction had been completed at seven bridges (nine slopes) in the Lower Keys (W. Buzick, DER, letter to J. Kraft, DOT, 7/20/82). Other bridge slopes were not to be treated due either to incomplete construction, adequate natural revegetation, or nesting Least Terns. The bridges north of Marathon, with the exception of Channel 5 (October 1982) had been completed by July 1981 and had slopes that were beginning to naturally revegetate by mid-1982.

In September 1982, DOT spread bagged, mowed mulch at the bridge sites specified by DER. Mulching (2-3 strips per slope) occurred primarily where unvegetated slopes abutted open water and included about 4,600 linear feet of causeway slope (Zeigler, DOT, letters to Lotspeich, DER, 7/28/92 and 9/27/82). In 1983, an additional 6,400 linear feet of causeway was mulched in strips on ten slopes near seven more bridges. A total of about 11,000 linear feet of newly filled approaches at 14 bridges in the Lower Keys was treated with the strip mower-mulch method from 1981 to 1983. The Department of Environmental Regulation absolved DOT of any further requirement for slope revegetation in a July 15, 1983 letter.

After more than ten years, it is probably impossible to determine the value and benefits of placing the mowed mulch on the slopes. Investigation should have been made on a frequent basis for the first year or two. Available photography from the same period indicates that the method was successful for at least a year or two in speeding revegetation where the mulch was placed. The benefit to stabilizing the extensive areas of fill not mulched cannot be determined.

To generally review the current conditions of slopes and their progress since 1983, and to determine the species of groundcovers present and their density, 44 slopes at 27 bridged (nine in the Upper Keys) were inspected from November 1992 to May 1993 (Table 9). A quadrat (0.25 m^2) was used to determine densities in representative areas. Over a wide range of conditions, densities ranged from 16 plants per square meter to 336 plants per square meter (Table 10). Diversity was relatively low with three to four dominant species at most sites. Because part of the study was conducted at the end of the Keys dry season (May), twelve slopes had dried grasses that were unidentifiable.

The most common plants present were *Spermacoe verticillata*, *Eustachys petraea*, *Tridax procumbens*, *Stylosanthes lamata*, and *Sporobolus poiretii*. Table 11 lists the plant species found at the donor sites in 1981. Table 12 lists plants documented on all of the slopes studied, mulched and unmulched. Of the five dominant species on the mulched slopes, only *Tridax procumbens* was also found at the donor sites in 1981. There was a total of 42 species of plants identified over all slopes; eight of these are species found in the donor areas. This is a low percentage of overlap, but successional stages have obviously resulted survival of the best groundcover for the conditions. A large seed source of pioneering plant species exists in the Keys and most are spread by wind or animals.

Photographs of many of the slopes were taken by DOT or DER between 1981 and 1985. Some of these were duplicated in May 1993 to compare the amount of groundcover (Table 13; Figures 6-17). A substantial increase in vegetation has occurred at all locations studied except near Whale Harbor, Indian Key, and Boca Chica Bridges. Some of these slopes are heavily traveled by vehicles pulling off the road to fish, snorkel, windsurf, etc. and are still essentially barren. In addition, on many slopes there is a barren, eroded zone immediately adjacent to the paved surface as a result of the absence of a paved pull-off lane. Harris Channel, Harris Gap Channel, Lower Sugarloaf Channel, and Saddlebunch No. 3 and No. 4 show an increase in vegetative cover, but it is patchy. Many of the slopes still consist of rock rubble, a difficult substrate for establishment of small plants, especially in combination with heat, intense solar radiation, desiccation, an extended dry season, and a relatively steep slope. Mowing of these slopes occurs mostly in the summer and fall wet seasons.

The increase in the speed of recovery of the vegetative cover at the experimental sites and the other sites treated with strips of mowed mulch indicates that mulching contributed to the project purpose of speeding recovery. The length of time it has taken for revegetation

Table 9. Grass sampling of revegetated bridge slopes, November 1992 — May 1993.

BRIDGE LOCATION	SIDE / AREA SAMPLED	BRIDGE LOCATION	SIDE / AREA SAMPLED
Whale Harbor	Key West Gulf	Kemp Channel	*Key West Gulf
	Key West Ocean		*Miami Gulf
Tea Table Channel	Key West Gulf	Bow Channel	*Miami Gulf
Indian Key Channel	Miami Ocean	Park Channel	*Miami Gulf
Lignum Vitae Channel	Miami Ocean	Harris Gap Channel	*Key West Gulf
Channel #2	Miami Ocean		*Miami Gulf
Channel #5	Key West Ocean	Harris Channel	*Key West Gulf
	Miami Ocean		*Miami Gulf
Long Key Channel	Key West Gulf	Lower Sugarloaf Channel	*Key West Gulf
	Miami Gulf		*Miami Gulf
Tom's Harbor Cut	Key West Gulf	Saddlebunch #2	Key West Gulf
	Miami Gulf		Miami Gulf
Tom's Harbor Channel	Key West Gulf	Saddlebunch #3	Key West Gulf
	Miami Gulf		Miami Gulf
Little Duck / Missouri Channel	Key West Ocean	Saddlebunch #4	Key West Gulf
	Miami Ocean		Miami Gulf
Bahia Honda Channel	Key West Gulf	Saddlebunch #5	Key West Gulf
North Pine Channel	*Miami Gulf		Miami Gulf
South Pine Channel	*Miami Gulf	Shark Channel	Key West Gulf
Torch Ramrod Channel	*Miami Gulf		Miami Gulf
Niles Channel	*Key West Gulf	Boca Chica Channel	Key West Gulf
	Miami Gulf		Miami Gulf

*slopes treated with mower mulch strips, 1981-1983.

Table 10. Density by species, bridge slope revegetation sites.

BRIDGE LOCATION	SIDE/AREA SAMPLED	DOMINANT SPECIES	DENSITY (units/m2)
WHALE HARBOR	KEY WEST OCEAN	*Spermacoce verticillata*	16
	KEY WEST GULF	*Flaveria linearis*	16
		Bidens alba	16
		Sporobolus poiretii	16
TEA TABLE CHANNEL	KEY WEST GULF	*Eustachys petraea*	80
INDIAN KEY CHANNEL	MIAMI OCEAN	*Ipomoea* spp.	16
		Spermacoce verticillata	64
LIGNUM VITAE CHANNEL	MIAMI OCEAN	*Eustachys petraea*	160
		Stylosanthes haviata	80
		Setaria geniculata	48
		Vigna luteola	48
CHANNEL #2	MIAMI OCEAN	*Spermacoce verticillata*	16
		Eustachys petraea	128
CHANNEL #5	MIAMI OCEAN	*Stylosanthes hamata*	160
	KEY WEST OCEAN	*Spermacoce verticillata*	16
		Tridax procumbens	176
LONG KEY CHANNEL	MIAMI GULF	*Eustachys petraea*	160
		Spermacoce verticillata	48
		Tridax procumbens	16
	KEY WEST GULF	*Spermacoce verticillata*	80
		Sporobolus poiretii	80
TOM'S HARBOR CUT	MIAMI GULF	*Tridax procumbens*	112
	KEY WEST GULF	*Spermacoce verticillata*	208
TOM'S HARBOR CHANNEL	MIAMI GULF	*Spermacoce verticillata*	64
		Tridax procumbens	32
	KEY WEST GULF	*Spermacoce verticillata*	80
		Tridax procumbens	32
LITTLE DUCK MISSOURI CHANNEL	MIAMI OCEAN	*Stylosanthes hamata*	16
	KEY WEST OCEAN	*Eustachys petraea*	64
		Tridax procumbens	80
		Stylosanthes hamata	80
BAHIA HONDA CHANNEL	KEY WEST GULF	Unid. dry grasses	
NORTH PINE CHANNEL	MIAMI GULF	*Spermacoce verticillata*	64
SOUTH PINE CHANNEL	MIAMI GULF	*Stylosanthes hamata*	128
TORCH RAMROD CHANNEL	MIAMI GULF	*Waltheria indica*	16
		Stylosanthes hamata	32
NILES CHANNEL	MIAMI GULF	*Tridax procumbens*	32
		Spermacoce verticillata	16
		Cassia nictitans	32
	KEY WEST GULF	*Waltheria indica*	32
		Spermacoce verticillata	48

(continued)

Table 10 continued.

BRIDGE LOCATION	SIDE/AREA SAMPLED	DOMINANT SPECIES	DENSITY (units/m2)
KEMP CHANNEL	KEY WEST GULF	*Tridax procumbens*	16
		Cassia nictitans	32
	MIAMI GULF	Unid. dry grasses	
BOW CHANNEL	MIAMI GULF	*Tridax procumbens*	16
PARK CHANNEL	MIAMI GULF	*Cassia nictitans*	32
HARRIS GAP CHANNEL	MIAMI GULF	*Stylosanthes hamata*	16
	KEY WEST GULF	*Stylosanthes hamata*	32
HARRIS CHANNEL	MIAMI GULF	*Tridax procumbens*	32
		Cassia nictitans	32
	KEY WEST GULF	*Stylosanthes hamata*	64
LOWER SUGARLOAF CHANNEL	MIAMI GULF	*Tridax procumbens*	32
	KEY WEST GULF	*Spermacoce verticillata*	64
SADDLEBUNCH #2	MIAMI GULF	*Tridax procumbens*	48
	KEY WEST GULF	Unid. dry grasses	
SADDLEBUNCH #3	MIAMI GULF	*Flaveria linearis*	16
	KEY WEST GULF	Unid. dry grasses	
SADDLEBUNCH #4	MIAMI GULF	Unid. dry grasses	
	KEY WEST GULF	Unid. dry grasses	
SADDLEBUNCH #5	MIAMI GULF	Unid. dry grasses	
	KEY WEST GULF	Unid. dry grasses	
SHARK CHANNEL	MIAMI GULF	Unid. dry grasses	
	KEY WEST GULF	Unid. dry grasses	
BOCA CHICA CHANNEL	MIAMI GULF	Unid. dry grasses	
	KEY WEST GULF	Unid. dry grasses	

to proceed on all other slopes is a function of many factors including age, soil texture, seed source, protection from wind, vehicular traffic, and others. Some parts of some slopes, even those without traffic, are still functionally unvegetated. The fact that this is the case even after 11-12 years indicates that some method of slope treatment should be developed to vegetate

Table 11. Species list for donor sites, bridge slope revegetation.

SITE	SCIENTIFIC NAME	COMMON NAME
1	*Borrichia frutescens*	sea daisy
	Eustachys petraea	finger grass
	Heliotropium curassavicum	seaside heliotrope
	Paspalum vaginatum	seaside jointgrass
	Cenchrus incertus	sandspur
	Sporobolus indicus	smutgrass
	Setaria geniculata	yellow foxtail grass
	Gaura angustifolia	gaura
	Dactyloctenium aegyptium	crowfoot grass
	Lippia nodiflora	capeweed
	Chamaesyce sp.	spurge
	Bidens pilosa	shepherd's needle
	Tribulus cistoides	puncture vine
	Conyza canadensis	horseweed
2	*Ipomoea pes-caprae*	railroad vine
	Bidens pilosa	shepherd's needle
	Conyza canadensis	horseweed
3	*Eustoma exaltata*	seaside gentian
	Sporobolus indicus	smutgrass
	Bidens pilosa	shepherd's needle
	Heliotropium curassavicum	seaside heliotrope
	Flaveria sp.	yellowtop
	Eustachys petraea	fingergrass
	Borrichia frutescens	sea daisy
	Cenchrus incertus	sandspur
4	*Heliotropium curassavicum*	seaside heliotrope
	Sporobolus indicus	smutgrass
	Sporobolus virginicus	seaside dropseed
	Tridax procumbens	tridax
	Stachytarpheta jamaicensis	blue porterweed
	Eustachys petraea	fingergrass
	Eustoma exaltata	seaside gentian
	Bidens pilosa	shepherd's needle
	Chamaesyce hypericoides	spurge
	Chamaesyce spp.	
	Sida acuta	indian hemp
	Borrichia frutescens	sea daisy
	Indigofera spicata	indigo
	Cenchrus incertus	sandspur
	Cynondon dactylon	Bermuda grass
5	*Setaria geniculata*	yellow foxtail grass
	Herissantia crispa	bladder mallow

(continued)

Table 11 continued.

SITE	SCIENTIFIC NAME	COMMON NAME
(5)	*Heliotropium angiospermum*	heliotrope
	Heliotropium curassavicum	seaside heliotrope
	Eustoma exaltata	seaside gentian
	Bidens pilosa	shepherd's needle
	Gaura angustifolia	gaura
	Flaveria sp.	yellowtop
	Cenchrus echinatus	sandspur
	Melanthera nivea	
	Atriplex arenaria	saltbush
	Conyza canadensis	horseweed
	Chamaesyce sp.	
	Cynodon dactylon	Bermuda grass
	Ageratum littorale	ageratum
	Stenotaphrum secundatum	St. Augustine grass

Table 12. Species list, bridge slope revegetation sites, 1992-93.

Agalinis obtusifolia Raf.
Albizzia lebbeck (L.) Benth.
Andropogon glomeratus (Walt.) BSP
Andropogon sp.
Bidens alba (L.) DC.
Bothriochloa pertusa (L.) A. Camus
Cassia nictitans L. var. *aspera* (Muhl. ex Elliott) Torr. & Gray
Chamaesyce blodgetti (Engelm. ex Hitchc.) Small
Chamaesyce hyssopifolia (L.) Small
Chamaesyce mesembryanthimifolia (Jacq.) Dugand
Chamaesyce porteriana Small?
Conocarpus erectus L.
Conyza candensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Desmodium tortuosum (Sw.) DC.
Eragrostris elliottii S. Wats.
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.
Flaveria linearis Lag.
Gaillardia pulchella Foug.
Galactia parvifolia A. Rich.
Galactia regularis (L.) BSP.
Galactia striata (Jacq.) Urban?
Gaura angustifolia Michx.
Ipomoea pes-caprae (L.) R. Br.
Ipomoea sp.
Leucaena leucocephala (Lam.) de Wit
Muhlenbergia capillaris (Lam.) Trin. or *M. expansa* (DC.) Trin.
Paspalum notatum Fleugge
Paspalum setaceum Michx.
Piscidia piscipula (L.) Sarg.
Rhynchelytrum repens (Willd.) C.E. Hubb.
Rhynchosia minima (L.) DC.?
Schinus terebinthifolius Raddi
Sesbania emerus (Aubl.) Urban
Setaria geniculata (Lam.) Beauv.
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Tridax procumbens L.
Vigna luteola (Facq.) Benth.
Waltheria indica L.

Table 13. Bridge slope revegetation locations photodocumented in 1981, 1985, 1993

BRIDGE LOCATION	PHOTOGRAPHED	1981	1985	1993
Whale Harbor	Key West Gulf	X		X
	Key West Ocean	X		X
Tea Table Channel	Key West Gulf	X		X
Indian Key Channel	Miami Ocean	X		X
Lignum Vitae Channel	Miami Ocean	X		X
Channel #2	Miami Ocean	X		X
Tom's Harbor Cut	Miami Gulf	X		X
Little Duck Missouri Channel	Key West Ocean		X	X
	Miami Ocean		X	X
North Pine Channel	Miami Gulf		X	X
Torch Ramrod Channel	Miami Gulf		X	X
Niles Channel	Key West Gulf		X	X
Kemp Channel	Key West Gulf		X	X
	Miami Gulf		X	X
Bow Channel	Miami Gulf		X	X
Park Channel	Miami Gulf		X	X
Harris Gap Channel	Miami Gulf		X	X
	Key West Gulf		X	X
Harris Channel	Miami Gulf		X	X
	Key West Gulf		X	X
Lower Sugarloaf Channel	Miami Gulf	X	X	X
	Key West Gulf	X	X	X
Saddlebunch #2	Miami Gulf	X	X	X
	Key West Gulf	X	X	X
Saddlebunch #3	Miami Gulf		X	X
Saddlebunch #4	Miami Gulf	X	X	X
	Key West Gulf	X		X
Saddlebunch #5	Miami Gulf	X		X
Shark Channel	Miami Gulf	X		X
Boca Chica Channel	Key West Gulf	X		X

LITERATURE CITED

Continental Shelf Associates, Inc. (CSA). 1982. Final Report — Seagrass Revegetation Studies in Monroe County. Fla. Dept. of Transportation FL-ER-20-82. 95 pp. + apps.

Crewz, D. and R. R. Lewis. 1991. An evaluation of historical attempts to establish emergent vegetation in marine wetlands in Florida. Florida Sea Grant College Publication Tech. Paper No. 60. 76 pp. + apps.

Derrenbacker, J. A. and R. R. Lewis. 1983. Seagrass habitat restoration, Lake Surprise, Florida Keys. Pp. 132-154 in R. H. Stovall (ed.), Proc. 9th Ann. Conf. Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Fla.

Fonseca, M. S. 1994. A guide to planting seagrasses in the Gulf of Mexico. Texas A&M University, TAMU-SG-94-601. 27 pp.

Goforth. H. W., Jr. 1984. Survival and growth of red mangroves (*Rhizophora mangle* L.) planted upon marl shorelines in the Florida Keys; a five-year study. Naval Ocean Systems Center Tech. Rep. 964. San Diego, Calif.

Jordan, W. R. 1986. The effects of re-establishing tidal circulation to a mangrove lagoon, Bahia Honda Key, Monroe County, Florida. Florida Dept. of Transportation, FL-ER-32-86. 189 pp.

Lewis, R. R. 1987. The restoration and creation of seagrass meadows in the southeast United States. Pp. 153-173 in M. J. Durako, R. C. Phillips, and R. R. Lewis III (eds.), Proceedings of the Symposium on Subtropical-Tropical Seagrasses of the Southeastern United States. Fla. Marine Research Institute Publ. No. 42, St. Petersburg.

Lewis, R. R. and R. C. Phillips. 1981. Experimental seagrass mitigation in the Florida Keys. Pp. 143-152 in R. C. Carey and J. B. Kirkwood (eds.), Proc. USFWS Workshop on Coastal Ecosystems of the Southeastern United States. FWS/OBS-80/59. U.S. Dept. of the Interior, Washington, D.C.

Mangrove Systems, Inc. 1985. Combined final report — Florida Keys Seagrass Restoration Project. Report to the Florida Dept. of Environmental Regulation, Tallahassee, Fla. 73 pp.

Suchanek, T. H. 1983. Control of seagrass communities and sediment distribution by *Callianassa* (Crustacea, Thalassinidea) bioturbation. J. Mar. Res. 441:281-298.

Thorhaug, A. 1979. Growth of restored *Thalassia* in a multiply impacted estuary. Pp. 263-276 in D. P. Cole (ed.), Proceedings of the Sixth Annual Conference on the Restoration and Cretion of Wetlands. Hillsborough Community College, Tampa, Fla.

Williams, S. L. 1990. Experimental studies of Caribbean seagrass bed development. Ecol. Monog. 60(4):449-469.

APPENDIX A

FLORIDA KEYS BRIDGE REPLACEMENT
MITIGATION PROGRAM
(Revised 9-15-82)

Program	Agency/Date	Commitments	Applicable Bridges	Status	Projected Completion Date	Estimated Total Cost (Cost-to-Date)	Remarks
Hydrological							
Mitigation Plan No.1	COE, 10/4/76 (EPA) (No State involvement)	1. Hydrological/Biological evaluation in Upper Keys re: causeways/hypersalinity.	Whale Harbor, Tavernier, Teatable Relief, Teatable, Indian Key, Lignum Vitae				1. Commitment renegotiated (trade off No.1 below) due to projected cost of study (± $500,000.00)
Trade Off Plan No.1	COE, 10/31/78 (EPA)	1. Partial causeway removal Snake Creek (350'±)	Same as COE No. 1, above.	Complete		($68,000.)	1. Complete
		2. Investigate feasibility of 4 culvert sites Cross Key		Complete		($15,000.)	2. Head insufficient for exchange to affect salinity
		3. Investigate feasibility of additional culvert site at Lake Surprise		Complete			3. Culverts not required
		4. Investigate benefits of causeway removal at Tavernier and Whale when 4-laning is required		Not required			4. Whale only pending 4-laning (not presently scheduled through 1987)
		5. Added 2/23/79, partial causeway removal at Tavernier at request of FHWA (190'±)		Complete		($75,000.)	5. Complete
						$158,000.	Program total
Seagrass Revegetation	DER, 12/13/76	1. Seagrass experimental test plot program (90000-1518)	Craig Key	Complete		$125,000. ($107,397.)	1. Complete
		2. Dredge site sump test for silt deposition	Shark Channel	Ongoing	1/83	$26,000. ($17,000.)	2. Final sampling 9/82. Final report by 1/83. Results applicable to backfill/dredge cut replanting requirements

Program	Agency/Date	Commitments	Applicable Bridges	Status	Projected Completion Date	Estimated Total Cost (Cost-to-Date)	Remarks
Seagrass Revegetation cont'd.		3. Seagrass revegetation dependent on results of experimental program and pre-construction inventory of grass loss.	All except Cow Key, Boca Chica, Indian Key, Teatable and Teatable Relief (32 bridges)	Pending	1/84	$150,000.	3. Final decision on replant dependent on interagency negotiations following receipt of final report Acreage lost range 25-50 acres.
	COE	1. Replant seagrass dependent on results of seagrass test program (No.1 above). 20 bridges	Harris to 7-Mile (inclusive, 16 bridges), Channel No.5, Channel No.2, Lignum Vitae, Snake Creek.	Pending	1/84		1. Same as FDER No.3, above
		2. Replant seagrasses to the maximum extent practical.	Long Key, Tom's Harbor, Tom's Harbor Cut.	Pending	1/84		2. Same as FDER No. 3, above
		3. Backfill dredge areas and plant seagrasses (7 bridges)	Rockland, Shark, Saddlebunch No.5, 4, 3, & 2. Lower Sugarloaf	Pending	1/84	$301,000.	3. Shark was only bridge dred ed. Backfill requirement eleminated 2/15/80. Replan ing to be based on negotiations, FDER No. 3, abov Estimated to complete program.
Mangrove Mitigation/ Recirculation (Trade Off No.2)	FDER, 12/13/76	1. Determination of permanently affected mangrove vegetation	All except Cow Key, Boca Chica, Whale Harbor, Indian Key, Teatable and Teatable Relief	Complete			1. Area affected on applicabl is 51.03 acres.
		2. Replacement of mangroves lost to construction		Complete			2. Seven bridges covered unde COE, below. Remainder cove ed by mitigation program (Trade-off No.2)

Program	Agency/Date	Commitments	Applicable Bridges	Status	Projected Completion Date	Estimated Total Cost (Cost-to-Date)	Remarks
Mangrove Mitigation/ Recirculation (Trade Off No.2) Continued.		3. On new fill, mangroves planted at toe of slope 1/5 lineal feet (Inter-agency agreement).	Same as No. 1, less Whale Harbor	Ongoing	11/83	$25,000. ($8,000.)	3. 33 bridges eligible, 5 (to date) require no treatmen all but 2 have received i itial planting
		4. Rubble berm construction	Same as No. 1	Ongoing	6/83	$155,000. (105,000.)	4. 42,250 feet of shoreline habitat created.
	COE, 7/1/77 FDER, 7/1/77	1. To plant mangroves at (total 19,600') sites listed in lieu of one/ one on seven bridges	Rockland, Shark, Lower Sugarloaf, Saddlebunch No. 5, 4, 3, 2.	Complete			
		a. Barnes Sound (3000')		Deleted			a. Poor substrate, high energy, pedestrian stresses.
		b. Bahia Honda (1400')		Complete			b. Successful
		c. Spanish Harbor (2550')		Complete			c. Atlantic successful; Gulf unsuccessful due high energy.
		d. Boca Chica Bridge Causeway (4650')		Complete			d. Successful
		e. Community College Road (8000')		Complete Complete			e. 30% successful due to poor substrate algal ma
	USCG, 9/26/77	1. Restore functional capacity of culverts BH	Tom's Harbor, Tom's Harbor Cut	Complete			1. Superceded by recircula-tion program.
		2. Replant BH impounded area with mangroves		Deferred	11/83	$32,000.	2. Deferred pending comple-tion of BH study and assessment of natural revegetation.
		3. Investigate feasibility of trade-off sites for re-circulation.		Complete			3. See recirculation program, below.

*incomplete data

Program	Agency/Date	Commitments	Applicable Bridges	Status	Projected Completion Date	Estimated Total Cost (Cost-to-Date)	Remarks
Recirculation (Trade-Off No.2)	COE,4/28/78, FDER	In lieu of one/one mangrove mitigation on the rest of the bridges the recirculaion program was developed.	20 bridges are included. Long Key, Tom's Harbor, Tom's Harbor Cut later added. Excluded were the 7 bridges in the planting program & Indian Key Teatable, Teatable Relief, Whale Tavernier, Cow Key, and Boca Chica.				
		1. Collect background data and hydrological changes on completion of culvert installation at one mitigation site and controls. (90000-1519) (Bahia Honda)		Ongoing	1/83	$215,320. ($204,556.)	1. Scheduled sampling completion 8/82. Final Report 1/83.
		2. Install swale-culvert Bahia Honda (6.6 acres) (90000-3522)		Complete		($28,475.)	
		3. Install culverts: (90000-3517)				$228,890. ($218,361.)	
		a. Boca Chica (596 acres)		Complete			
		b. Lower Sugarloaf (107 acres)		Complete			
		c. Cudjoe Key (211 acres)		Complete		$684,685*	Estimated to complete program (Mangrove & Recirculation)

*Incomplete data

Program	Agency/Date	Commitments	Applicable Bridges	Status	Projected Completion Date	Estimated Total Cost (Cost-to-Date)	Remarks
Approach Fill Stabilization	FDER	1. Revegetate (stabilize) approach fill slopes.	All	Deferred		$8,500. ($4,100.)	1. 37 bridges surveyed wee[illegible] of July 20, 1982. No apparent erosion noted. slopes will receive su[illegible] plementary native seedi[illegible] this fall (1982). Cost reflects accomplishment FDOT personnel using sl[illegible] revegetation treatment established thru test p[illegible] during the preceding ye[illegible]
Turbidity Research (99700-7213)	FDOT/UF	1. Evaluate the effects of Turbidity on biological communities.		Complete		($40,000.)	
Keys Mitigation (90000-1513)			All	Complete		($384,585.)	1. This amount was applica[illegible] to all Keys Mitigation [illegible] grams through 5/80. Pre[illegible] separation to *Hydrologi[illegible]* mangrove,seagrass,etc., programs is not possib[illegible]
Environmental Studies (90000-1504)	FHWA,1/76, FDOT		All	Complete		($233,500.)	
						$1,808,270.*	Grand total to complete the program

*Incomplete data

APPENDIX B

MEMORANDUM OF AGREEMENT

The Florida Department of Transportation, hereinafter referred to as DOT, and the Florida Department of Environmental Regulation, hereinafter referred to as DER, do hereby enter into this Interagency Memorandum of Agreement on this 13th day of December 1976, for the purpose of the protection from and mitigation for potential environmental damages resulting from the replacement construction of thirty-seven (37) bridges on the overseas highway, US-1, Monroe County, Florida.

This Agreement will satisfy those mitigative measures that are anticipated as portions of permit stipulations by the DER on each project location that pertain to the loss and reestablishment of desirable wetland and submerged vegetation adversely affected by the construction process. Other permit stipulations concerning design and construction features of the proposed bridge structures and their attending roadway approaches are not precluded by this Agreement; such stipulations will be determined on a case-by-case basis.

I

The Florida Department of Transportation recognizes its environmental responsibilities attendant to the implementation of the above-mentioned construction program. In recognition of those responsibilities, the DOT will utilize for the duration of the construction program a team of qualified biologists to assess potential environmental damages to submerged wetland vegetation. The assessments will quantify on a standing crop basis areal amounts of vegetation that will be adversely affected by the construction process on a project-by-project basis. Each assessment will be subject to review and verification by the DER.

II

In order that those areas of wetlands vegetation may be protected to the maximum extent possible, the DOT will require the construction Contractor to accomplish the following at each project location:

1. In all tidal areas where construction may result in increased turbidity of surrounding waters, turbidity barriers shall be employed. Barriers shall be placed to contain movement of suspended sediments within the limits of construction.

Where submerged aquatic grasses are present, a riprap barrier shall be constructed along the seaward limits of embankment fill in order to prevent slippage of fill material beyond construction limits. The riprap barrier shall extend the entire length of area to be filled where the toe of slope occurs below MLW. The riprap barrier shall be of sufficient elevation and strength to contain all fill within the limits of construction. Turbidity barriers shall be placed outside riprap barriers in order to prevent sagging of or damage to the turbidity barrier from accumulated silts at the base of the barrier.

2. Where so directed by the Project Engineer (DOT) the following types of vegetation within the DOT right-of-way shall be protected and left standing:

Red Mangrove - *Rhizophora mangle*

White Mangrove - *Laguncularia racemosa*

Black Mangrove - *Avicennia germinans*

Unless otherwise authorized by the Project Engineer, all vegetation will be left standing from at least five feet landward (horizontal measure) of the seaward limit of those sections of roadway embankment of a 4h:1v or flatter slope.

Selective clearing will be required in all areas outside the toe line of a theoretical 2h:1v slope measured from the shoulder point. No grubbing or removal of stumps and root material will be accomplished in this area.

At the toe of the fill slope and in shallow fills, vegetation will be allowed to protrude through the fill material so as to encourage natural reestablishment of the species. The toe of the slope will be varied by truncating the outer limits of the fill slopes thereby minimizing disruption of existing plant growth.

Where new fill is placed creating barren wetland margins subject to periodic innundation from tidal activity, slopes will be vegetated with appropriate mangrove vegetation. Slope preparation will require the construction of a swale protected by a rubble berm within the intertidal limits of the slope. Within this swale a dense mat of seagrass litter containing mangrove seed will be strewn.

One (1) year following seed planting a joint evaluation by the DOT, DER, and the Department of Natural Resources, will determine the success of the seeding operation. If it is determined that mangrove establishment has not been achieved to a desirable extent, seedlings will be planted along the intertidal slope at a density of at least one (1) seedling for each five (5) lineal feet of shoreline. Additional plantings may be desirable where suitable areas may be located within DOT right-of-way.

The extent of the mangrove replacement will be based on the standing crop assessment of mangrove vegetation permanently affected by the construction process. Areal amounts of mangroves replaced shall duplicate to the nearest extent possible the amount of vegetation permanently lost to the construction process.

IV

Based on the inventory information accumulated at each project location, an areal determination of permanently affected submerged marine vegetation will be made. The DOT will attempt to revegetate barren submerged lands in like amounts to the extent possible under the advice and supervision of the DER and the Department of Natural Resources. The planting program will be pursued in the following manner:

1. A literature survey will be done by DOT personnel in order to determine the state of the art in seagrass revegetation research.

2. Areas will be selected for test plots by the DER and the DOT which appear most conducive to successful seagrass establishment. Criteria for test plot locations shall duplicate as nearly as possible areas that exhibit healthy vegetative stands.

3. Test plots will be planted by sprigging and/or seeding and shall be monitored by the DER and the DOT for one (1) full year. If it is determined that the experimental plots are successful, additional areas will be vegetated to the extent indicated by the inventory of vegetation made by the DOT.

4. An additional test site for submerged grasses shall be provided in an area agreed upon by the DOT and the DER whereby a shallow sump shall be dredged in an area of barren rock or course sediment not conducive to rooted vegetation. This site will be monitored for at least two (2) years to determine the following:

   a. That the sump will trap silt over time to an adequate extent that a suitable substrate will accumulate for vegetation establishment and,

   b. That natural vegetation may occur under the above provided conditions.

If the sump test site is deemed successful, the DOT will provide other such areas upon the advice and consent of the DER.

V

The mitigative efforts outlined in this Agreement will be a continuing process until one (1) year following the completion of the construction program. Funding for all mitigative efforts will be provided by the DOT.

VI

This Agreement is reached with the understanding that mitigation is to be considered a remedy of last resort failing suitable project modifications to avoid adverse impacts at each bridge site.

The Department of Environmental Regulation will review each permit application and make recommendations for modifications other than mitigation where appropriate, as indicated by Water Quality Reports, Biological and Hydrographic Surveys, and the review of other relevant data.

STATE OF FLORIDA
DEPARTMENT OF TRANSPORTATION

By: Tom Webb Jr.
Secretary

STATE OF FLORIDA, DEPARTMENT
OF ENVIRONMENTAL REGULATION

By: J.W. Landers Jr.
Secretary

Approved:
J.W.B.
Director of the Division
of Road Operations

11/16/76
(Date)

APPENDIX C

MEMORANDUM OF AGREEMENT

THIS MEMORANDUM OF AGREEMENT entered into this 8th day of April, 1977, by and between the DEPARTMENT OF NATURAL RESOURCES a component agency of the State of Florida, hereinafter referred to as "The Agency" and THE DEPARTMENT OF TRANSPORTATION, also a component agency of the State of Florida, hereinafter referred to as the "Department";

W I T N E S S E T H:

WHEREAS, The Department has initiated a program to replace thirty-seven (37) bridges in Monroe County, Florida, hereinafter referred to as "The Keys Bridges Replacement Program"; and

WHEREAS, The Department recognizes that certain unavoidable adverse environmental impact to submerged and wetland marine vegetation will occur during the course of construction of the replacement bridges; and

WHEREAS, The Department is desirous of mitigating adverse impact to marine submerged and wetland vegetation insofar as is practicable; and has signed an Interagency Mitigation Agreement with the Department of Environmental Regulation to that effect which is made a part of this Agreement; and

WHEREAS, The Agency has scientific facilities and personnel qualified to make determinations on technique and habitat requirements for establishing seagrasses and mangrove vegetation in non-vegetated areas; and

WHEREAS, The Department requires the services of The Agency in order to implement mitigation procedures outlined in the Interagency Mitigation Agreement above; and

WHEREAS, information and knowledge gained from implementation of a mitigation program may be used by The Agency to supplement its research efforts in seagrass propagation; and

NOW, THEREFORE, THIS INDENTURE WITNESSETH: That the parties hereto, for and in consideration of the covenants hereinafter set forth, do mutually agree as follows:

ARTICLE I

The purpose of this Agreement is to permit The Agency, upon request by The Department, to send qualified personnel to specific areas of the State to advise The Department concerning techniques for propagation of seagrass and mangrove vegetation, selection of suitable propagation sites and evaluation of propagation attempts. The Department may also request Agency personnel to attend formal meetings concerning mitigation endeavors attendant to the Keys Bridges Replacement Program. Information gained may be used to supplement the Agency's research on marine vegetation and will assist The Department in fulfilling its obligations as set forth in the Interagency Mitigation Agreement.

ARTICLE II

Duration of Agreement

This Agreement shall continue in force so long as the Agency and the Department desire or until one year following the completion of the Keys Bridges Replacement Program. The Agency or the Department may withdraw from the provisions of this Agreement by written notice at least thirty (30) days before the effective date of such termination. Should the Agency or the Department deem it necessary to terminate this Agreement by written notice, the Agency shall be compensated for its services rendered up to the time of the termination.

ARTICLE III

Payment of Costs

The Department hereby pledges to pay the Agency upon billing thereof, for costs involving travel expenses, lodging, and meals due to specific requests by the Department for personnel services by the Agency as outlined in Article I above. Payment for said costs shall not exceed a sum total of four thousand ($4,000.00) dollars for any single fiscal year within the duration period of this Agreement.

ARTICLE IV

Procedures

Procedure for requests for Agency services and payment for expenses incurred shall be as follows:

IN WITNESS WHEREOF, the parties hereto have executed this Agreement by and through their duly authorized executive officers, the day and year first above written.

DEPARTMENT OF TRANSPORTATION

By: Tom Webb Jr.

ATTEST: Carolyn Scarantino (SEAL)
Secretary

3-24-77

DEPARTMENT OF NATURAL RESOURCES

By: [illegible]

TITLE: Exec. Director

ATTEST: Mary C. Horak (SEAL)

TITLE: Exec. Secretary

APPROVED AS TO FORM AND LEGALITY:

By: [illegible]

TITLE: [illegible]

APPROVED:

Jay W. Brown
Director of Road Operations

APPROVED AS TO FORM AND LEGALITY
[illegible]
ATTORNEY - D.N.R

IN WITNESS WHEREOF, the parties hereto have executed this Agreement by and through their duly authorized executive officers, the day and year first above written.

DEPARTMENT OF TRANSPORTATION

By: Tom Webb Jr

ATTEST: Carolyn Scarola (SEAL)
Secretary

3-24-77

DEPARTMENT OF NATURAL RESOURCES

By: Harmon W. Shields

TITLE: Exec. Director

ATTEST: Mary C. Novak (SEAL)

TITLE: Exec. Secretary

APPROVED AS TO FORM AND LEGALITY:

By: ____________________

TITLE: ____________________

APPROVED:

Jay W. Brown
Director of Road Operations

APPROVED AS TO FORM AND LEGALITY
ATTORNEY - D.N.R

CERTIFICATE

STATE OF FLORIDA)

COUNTY OF LEON)

I HEREBY CERTIFY that the above and foregoing is a true copy of the original presented to me this 1st day of September, 1977.

Tina T. Pepper
Notary Public

Notary Public, State of Florida at large
My Commission Expires Jan. 11, 1980
Bonded by American Fire & Casualty Co.

indemnification agreement does not cover or indemnify the Department for its own negligence or breach of contract.

ARTICLE VII

Assignment

The Agency and the Department each bind themselves and their successors to the obligations respectively assumed by each hereunder. Neither party shall assign, sublet, or transfer its interest under this Agreement without prior written consent of the other.

ARTICLE VIII

Statutory Requirements

In the event this contract is in excess of $25,000 or has a term for a period of more than one year, the provisions of Chapter 334.21(8)(a), Florida Statutes, are hereby incorporated.

> "(a) The Department shall not, during any fiscal year, expend money, incur any liability, or enter into any contract which, by its terms, involves the expenditure of money in excess of the amounts budgeted as available for expenditure during such fiscal year. Any contract, verbal or written, made in violation of this subsection shall be null and void, and no money shall be paid thereon. The Department shall require a statement from the Comptroller of the Department that funds are available prior to entering into such contract or other binding commitment of funds. Nothing herein shall prevent the making of contracts for a period exceeding one year, but any contract so made shall be executory only for the value of the services to be rendered or agreed to be paid for in succeeding fiscal years, and this paragraph shall be incorporated verbatim in all contracts of the Department in excess of twenty-five thousand dollars and having a term for a period of more than one year."

(1) The Department will provide to the Agency the names, titles, and signatures of persons authorized to request personnel services from the Agency and approve payment for expenses incurred by such personnel as a result of the services performed.

(2) Prior to the Agency performing any services, the Department will notify in writing the Agency of services needed.

(3) Upon receipt of said request, the Agency will arrange for appropriate personnel to be made available to perform on site advisory services as specified in the Department's request.

(4) The Agency will arrange for all travel and per diem expenses for its representative or representatives.

(5) Following completion of services by Agency personnel requiring said travel and per diem expenses, the Agency shall bill the Department for the costs of travel and per diem expenses incurred.

(6) The Department will reimburse the Agency within thirty (30) days of receipt of billing from the Agency.

ARTICLE V

Conferences

The closest collaboration and cooperation shall be maintained between the Department and the Agency at all times; and the Department will be entitled to be advised of the status of work being done by the Agency as pertains to services rendered under Article I.

ARTICLE VI

To the extent allowed by law, the Agency hereby agrees to indemnify, defend, save, and hold harmless the Department from all claims, demands, liabilities, and suites of any nature whatsoever arising out of, because of, or due to the breach of this Agreement by the Agency, its agents, or employees or due to any act or occurrence of omission or commission of the Agency, its agents, or employees. It is specifically understood and agreed that this

APPENDIX D

SUPPLEMENTAL
MEMORANDUM OF AGREEMENT

The Florida Department of Environmental Regulation (DER) and the Florida Department of Transportation (DOT) enter into the following Supplemental Memorandum of Agreement, and state as follows:

1. On December 31, 1976, the DOT and DER entered into an Interagency Memorandum of Agreement for the purpose of minimizing and mitigating the adverse environmental impacts resulting from the replacement construction of thirty-seven (37) bridges on the Overseas Highway, U.S. 1, in Monroe County, Florida.

2. The provisions of the Memorandum of Agreement were subsequently incorporated by reference as conditions of construction permits issued to DOT for the Florida Keys Bridges Replacement Program. Specific conditions of that Memorandum of Agreement pertaining to submerged marine vegetation were also incorporated by reference in construction permits issued by the U.S. Corps of Engineers and the U.S. Coast Guard.

3. Paragraph IV of said Memorandum of Agreement (a copy of which is attached hereto as Appendix A) provided that DOT would undertake a mitigation plan with the expressed purpose of replacing or restoring submerged marine vegetation in like amounts to that adversely impacted or destroyed by the bridge replacement construction activity.

4. To date approximately fifty-one (51) acres of seagrasses have been disrupted or eliminated by permitted construction activity.

5. In furtherance of this mitigation effort, DOT has conducted an experimental seagrass planting program from February 1979 to February 1981, which has included the compilation of technical and economic feasibility data for further mitigation activities and methodologies.

6. By Memorandum of Agreement dated April 8, 1977, between DOT and the Department of Natural Resources (DNR), DNR agreed to provide professional expertise regarding appropriate sites and

methods of seagrass mitigation.

7. In consideration of the foregoing data, and in view of current funding restraints, modification of the scope of the original seagrass planting program is required in order for DOT to fulfill its obligations for environmental mitigation to the maximum extent possible within the limits of available resources.

WHEREFORE, in consideration of the foregoing,

IT IS AGREED that:

A. Within thirty (30) days from the execution of this agreement, DOT shall transfer funds to the DER Pollution Recovery Fund in the amount of Two Hundred Thousand Dollars ($200,000) for purposes of an alternative mitigation program.

B. DER agrees to administer such funds and to implement a plan of mitigation designed to restore or replace seagrasses affected by the Bridge Replacement Program to the maximum extent feasible. Where it is determined by the DER that the replacement or replanting of seagrasses is either technically or economically infeasible, by reason of water depths, currents, sediment composition or other ecological or economic consideration, it is understood and agreed that such funds may be utilized to carry out alternative mitigation efforts which will enhance or benefit the marine and aquatic environment of the Florida Keys, with preference being given to those areas or resources adversely impacted by bridge construciton activities.

C. DER shall advise DOT in writing periodically, but not less than semi-annually, as to the progress of mitigation activities undertaken pursuant to this Memorandum of Agreement.

D. DER and DOT agree that the transfer of funds shall constitute satisfaction and fulfillment of DOT obligations as contained in Paragraph IV.3 of the December 13, 1976, Memorandum of Agreement and those permit conditions relating to seagrass mitigation for the Florida Keys Bridge Replacement Program.

E. The availability of such funds for mitigation efforts, however, shall not be construed to relieve the DOT or other parties of any obligation or liability not specifically set forth herein.

F. It is understood and agreed by DOT and DER that this Supplemental Memorandum of Agreement shall set forth the means by which those permit conditions relating to seagrass mitigation set forth in thirty-seven construction permits issued to DOT by the DER may be fulfilled.

IN WITNESS WHEREOF the parties hereto have caused these presents to be executed this 18th day of October 1982.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION	STATE OF FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION
Director of Administration	Secretary
Attest:	Attest:

APPROVED ______________
Director of Construction-Date

OCT 14 1982
FUNDS AVAILABLE
APPROVED FISCAL

APPENDIX E

SPECIES FOUND ON EACH BRIDGE SLOPE

TORCH RAMROD/MIAMI GULF

Andropogon glomeratus (Walt.) BSP.
Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Conocarpus erectus L.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.
Flaveria linearis Lag.
Spermacoce verticillata L.
Stylosanthes hamata (L.) Taubert
Waltheria indica L.

SADDLE BUNCH #2/MIAMI GULF

Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Conyza canadensis (L.) Cronq.
Tridax procumbens L.

KEMP CHANNEL/MIAMI GULF

Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Spermacoce verticillata L.
Stylosanthes hamata (L.) Taubert
Sesbania emerus (Aubl.) Urban

BAHIA HONDA/KEY WEST GULF

Conyza canadensis (L.) Cronq.
Gaillardia pulchella Foug.
Schinus terebinthifolius Raddi
Stylosanthes hamata (L.) Taubert

CHANNEL #5/MIAMI OCEAN

Andropogon glomeratus (Walt.) BSP.
Bothriochloa pertusa (L.) A. Camus
Dactyloctenium aegyptium (L.) Beauv.
Rhynchosia minima (L.) DC. ?
Spermacoce verticillata L.
Stylosanthes hamata (L.) Taubert

KEMP CHANNEL/KEY WEST GULF

Stylosanthes hamata (L.) Taubert
Waltheria indica L.
Unknown Specimen #1

SADDLE BUNCH #2/KEY WEST GULF

Andropogon glomeratus (Walt.) BSP.
Dactyloctenium aegyptium (L.) Beauv.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert

CHANNEL #5/KEY WEST OCEAN

Andropogon glomeratus (Walt.) BSP.
Ipomoea pes-caprae (L.) R. Br.
Schinus terebinthifolius Raddi
Stylosanthes hamata (L.) Taubert
Waltheria indica L.

PARK CHANNEL/MIAMI GULF

Bidens alba (L.) DC.
Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Chamaesyce blodgettii (Engelm. ex Hitchc.) Small
Chamaesyce hyssopifolia (L.) Small
Fimbristylis spathacea Roth.
Piscidia piscipula (L.) Sarg.
Spermacoce verticillata L.
Waltheria indica L.

BOW CHANNEL/MIAMI GULF

Andropogon glomeratus (Walt.) BSP.
Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Conocarpus erectus L.
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Spermacoce verticillata L.
Stylosanthes hamata (L.) Taubert

HARRIS GAP/KEY WEST GULF

Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Galactia regularis (L.) BSP.
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.

Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Waltheria indica L.

SADDLE BUNCH #3/MIAMI GULF

Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.
Stylosanthes hamata (L.) Taubert

LITTLE DUCK MISSOURI/MIAMI OCEAN

Andropogon glomeratus (Walt.) BSP.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.
Stylosanthes hamata (L.) Taubert

SHARK CHANNEL/MIAMI GULF

Fimbristylis spathacea Roth.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Tridax procumbens L.

SHARK CHANNEL/KEY WEST GULF

Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Tridax procumbens L.

CHANNEL #2/MIAMI OCEAN

Andropogon glomeratus (Walt.) BSP.
Chamaesyce porteriana Small ?
Eustachys petraea (Sw.) Desv.
Ipomoea sp.
Spermacoce verticillata L.
Stylosanthes hamata (L.) Taubert

HARRIS GAP/MIAMI GULF

Andropogon glomeratus (Walt.) BSP.
Chamaesyce hyssopifolia (L.) Small
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.

Piscidia piscipula (L.) Sarg.
Schinus terebinthifolius Raddi
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert

LIGNUM VITAE/MIAMI OCEAN

Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Vigna luteola (Facq.) Benth.
Waltheria indica L.

NORTH PINE CHANNEL/MIAMI GULF

Eustachys petraea (Sw.) Desv.
Leucaena leucocephala (Lam.) de Wit
Spermacoce verticillata L.
Stylosanthes hamata (L.) Taubert

SOUTH PINE CHANNEL/MIAMI GULF

Andropogon glomeratus (Walt.) BSP.
Bidens alba (L.) DC.
Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Conocarpus erectus L.
Conyza canadensis (L.) Cronq.
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.
Flaveria linearis Lag.
Spermacoce verticillata L.
Stylosanthes hamata (L.) Taubert
Tridax procumbens L.

TEA TABLE/KEY WEST GULF

Andropogon glomeratus (Walt.) BSP.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.
Rhynchelytrum repens (Willd.) C.E. Hubb.
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert

WHALE HARBOR/KEY WEST GULF

Spermacoce verticillata L.

WHALE HARBOR/KEY WEST GULF

Andropogon sp.
Chamaesyce porteriana Small ?
Flaveria linearis Lag.
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert

LITTLE DUCK MISSOURI/KEY WEST OCEAN

Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Galactia striata (Jacq.) Urban ?
Ipomoea pes-caprae (L.) R. Br.
Stylosanthes hamata (L.) Taubert
Waltheria indica L.

HARRIS CHANNEL/MIAMI GULF

Andropogon glomeratus (Walt.) BSP.
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Galactia parvifolia A. Rich.
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Waltheria indica L.

LONG KEY/MIAMI GULF

Andropogon glomeratus (Walt.) BSP.
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Possibly Muhlenbergia capillaris (Lam.) Trin. or M. expansa (DC.) Trin. ???
Stylosanthes hamata (L.) Taubert
Tridax procumbens L.
Unknown specimen #2

SADDLE BUNCH #5/KEY WEST GULF

Spermacoce verticillata L.
Stylosanthes hamata (L.) Taubert

TOM'S HARBOR/KEY WEST GULF

Andropogon glomeratus (Walt.) BSP.
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Leucaena leucocephala (Lam.) de Wit
Stylosanthes hamata (L.) Taubert
Waltheria indica L.

TOM'S HARBOR/MIAMI GULF

Albizzia lebbeck (L.) Benth.
Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Conyza canadensis (L.) Cronq.
Eustachys petraea (Sw.) Desv.
Galactia regularis (L.) BSP.
Stylosanthes hamata (L.) Taubert
Waltheria indica L.

NILES CHANNEL/MIAMI GULF

Andropogon glomeratus (Walt.) BSP.
Bidens alba (L.) DC.
Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Piscidia piscipula (L.) Sarg.
Spermacoce verticillata L.
Waltheria indica L.

TOM'S HARBOR CUT/ KEY WEST GULF

Andropogon glomeratus (Walt.) BSP.
Bidens alba (L.) DC.
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Desmodium tortuosum (Sw.) DC.
Eustachys petraea (Sw.) Desv.
Spermacoce verticillata L.
Stylosanthes hamata (L.) Taubert

TOM'S HARBOR CUT/MIAMI GULF

Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Spermacoce verticillata L.
Waltheria indica L.

INDIAN KEY CHANNEL/MIAMI OCEAN

Andropogon glomeratus (Walt.) BSP.
Bothriochloa pertusa (L.) A. Camus
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Waltheria indica L.

LONG KEY/KEY WEST GULF

Bidens alba (L.) DC.
Desmodium tortuosum (Sw.) DC.
Eustachys petraea (Sw.) Desv.
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Tridax procumbens L.

SADDLE BUNCH #5/MIAMI GULF

Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Chamaesyce blodgettii (Engelm. ex Hitchc.) Small
Conyza canadensis (L.) Cronq.
Eustachys petraea (Sw.) Desv.
Stylosanthes hamata (L.) Taubert

SADDLE BUNCH #4/KEY WEST GULF

Eustachys petraea (Sw.) Desv.
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert

SADDLE BUNCH #4/MIAMI GULF

Andropogon glomeratus (Walt.) BSP.
Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.
Gaura angustifolia Michx.
Spermacoce verticillata L.

NILES CHANNEL/KEY WEST GULF

Andropogon glomeratus (Walt.) BSP.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Fimbristylis spathacea Roth.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Waltheria indica L.

SADDLE BUNCH #3/KEY WEST GULF

Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Flaveria linearis Lag.
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert

LOWER SUGARLOAF/MIAMI GULF

Agalinis obtusifolia Raf.
Chamaesyce mesembryanthimifolia (Jacq.) Dugand
Conyza canadensis (L.) Cronq.
Dactyloctenium aegyptium (L.) Beauv.
Eustachys petraea (Sw.) Desv.
Stylosanthes hamata (L.) Taubert

HARRIS CHANNEL/KEY WEST GULF

Agalinis obtusifolia Raf.
Andropogon glomeratus (Walt.) BSP.
Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Paspalum setaceum Michx.
Setaria geniculata (Lam.) Beauv.
Spermacoce verticillata L.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert

BOCA CHICA/KEY WEST GULF

Agalinis obtusifolia Raf.
Andropogon glomeratus (Walt.) BSP.
Bidens alba (L.) DC.
Bothriochloa pertusa (L.) A. Camus
Eustachys petraea (Sw.) Desv.
Sporobolus poiretii (R. & S.) Hitchc.

BOCA CHICA/MIAMI GULF

Andropogon glomeratus (Walt.) BSP.
Bidens alba (L.) DC.
Eragrostis elliottii S. Wats.
Eustachys petraea (Sw.) Desv.
Paspalum notatum Fleugge
Paspalum setaceum Michx.
Sesbania emerus (Aubl.) Urban
Setaria geniculata (Lam.) Beauv.

LOWER SUGARLOAF/KEY WEST GULF

Andropogon glomeratus (Walt.) BSP.
Cassia nictitans L. var. aspera (Muhl. ex Elliott) Torr. & Gray
Ipomoea pes-caprae (L.) R. Br.
Sporobolus poiretii (R. & S.) Hitchc.
Stylosanthes hamata (L.) Taubert
Waltheria indica L.