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The Restoration and Creation of Seagrass Meadows in the Southeast United States

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ABSTRACT

The restoration and creation of seagrass meadows is of increasing concern in the southeast United States, due to large scale declines in seagrass meadow coverage. Researchers and environmentalists estimate that approximately one-third of the 600,000 ha of seagrass meadows that were present in coastal Florida in the 1940's no longer exist. Associated declines in fisheries harvests have been documented. In Mississippi, 1,970 ha of seagrasses remain, representing a loss of almost two-thirds. Both restoration and creation of meadows have been successful in individual projects at sites up to 6 ha in size, but failures are common. A more analytical approach to successful plantings is encouraged; prior knowledge of water quality and stresses on existing seagrass meadows is essential. Simple transplanting with plugs from existing healthy meadows (particularly *Thalassia testudinum* plugs) is not encouraged for large-scale projects. The use of non-destructive sources of material for culture of planting units is documented and recommended. Salvage of seagrasses from areas to be impacted can ensure successful, non-destructive meadow restoration and creation, and is encouraged.

INTRODUCTION

Seagrass meadows in the southeast United States, particularly in Florida, provide critical marine habitat for many important commercial and recreational fisheries species, including scallops, spotted seatrout, snook, redfish, and pink shrimp (Gilmore et al., 1983; Tabb and Manning, 1961; Thayer et al., 1979; Zieman, 1982). Seagrasses are also an important food source for the endangered West Indian manatee (Hartman, 1979). Historical losses of seagrass meadows have been substantial: in Florida, 43% of the original seagrass cover in northern Biscayne Bay has been lost (Harlem, 1979), 81% in Tampa Bay (Lewis et al., 1985a), and 29% in Charlotte Harbor (Harris et al., 1983). In Mississippi Sound, a 59% loss has been documented (Eleuterius, 1976).

Reasons for these declines include dredging and filling for waterfront property and port development (Taylor and Saloman, 1968; Lewis, 1977; Harlem, 1979), and water quality degradation due to silt resuspension and eutrophication, which reduce light penetration (Harris et al., 1983; Lewis et al., 1985a). The former problem is now largely regulated, but the latter is not, and further losses of seagrass meadows due to general eutrophication of Florida's marine waters can be expected. In Mississippi, freshwater-diversion-reduced salinities (average of 4‰ over a 3-month period during 1973) in much of Mississippi Sound have decimated existing seagrass meadows (Eleuterius and Miller, 1976).

Partially as a result of these large-scale losses of seagrass habitat, marine productivity in Florida, defined in terms of the commercial harvest of estuarine-dependent species, has declined (Harris et al., 1983; Lewis et al., 1985b). Impacts to recreational fisheries are probably substantial, but are unquantified. However, when asked in interviews, saltwater recreational fishermen generally believe that their harvests have also declined (Bell et al., 1982).

Such declines in harvests have generated keen interest in restoration of lost marine habitat in general, and of tidal marshes, mangrove forests, and seagrass meadows in particular (Lewis, 1982a). The technology to restore or create tidal marshes and mangrove forests in the southeast has been under study for over 10 years, and techniques for tidal the fact that the three species most commonly used in restoration efforts (in Florida) have different rates of asexual reproduction; thus, numbers of shoots from established planting units vary widely with location and species.

TYPES OF PLANTING UNITS AND TECHNIQUES OF INSTALLATION

Four basic types of seagrass planting units are available: plugs, sprigs, seeds/seedlings, and cultivated plants (Table 1). Each of these has several synonyms, which are given below, and each has been utilized with special anchoring methods, as well as unanchored. Anchoring methods are discussed following descriptions of the basic types of planting units.

PLUGS

Plugs are also referred to as sods, clumps, and turfs. These different terms refer to shapes and sizes: sods are typically thin and square; clumps are thicker and irregularly shaped. All terms refer to intact units of native sediment, roots, rhizomes, and leaves. Plugs may be excavated with shovels, post-hole diggers (Van Breedveld, 1975), specially designed plugging tools (Lewis et al., 1982; Phillips et al., 1978; Ranwell et al., 1974), or large, barge-mounted excavators (Gaby et al., 1986). Sizes range from 10 cm to 23 cm in cross-section.

Installation of plugs usually involves excavating a hole slightly larger than the planting unit, placing the unit into the hole, and backfilling with surrounding sediment. Often, the same device used to remove the plug is used to create the hole for planting.

The site from which plugs are removed is referred to as a donor site, if it will remain intact after plug removal, or salvage site, if it is to be destroyed. In order to avoid permanent damage to a donor site, plugs selected for removal should not be in close proximity to one another. Spacing of plug removal is variously recommended to be 0.5 m to 0.9 m (Phillips et al., 1978; Van Breedveld, 1975).

SPRIGS

Sprigs are also known as vegetative shoots or turions. They consist of excavated intact roots, rhizomes, and leaves, but are free of sediments. Sprigs may also consist of similar units collected from wrack lines, or stoloniferous aerial runners (Derrenbacker and Lewis, 1983; Fonseca et al., 1985a) (Figure 1).

Sprigs used as planting units may be selected to include only those with apical meristems (Fonseca et al., 1987). If sprigs are harvested by excavation, only a portion of those recovered will be suitable for use, and sprigs without apical meristems would be discarded.

SEEDS/SEEDLINGS

Four of the seven species of seagrasses that occur in the southeast are documented to produce seeds or seedlings (McMillan, 1981; Phillips, 1960): *Thalassia testudinum* Banks ex König (turtle grass), *Halodule wrightii* Aschers. (shoal grass), *Syringodium filiforme* Kützing (manatee grass), and *Ruppia maritima* L. (widgeon grass). Only *Thalassia* seedlings and *Ruppia* seeds have been found in quantities sufficient for use in restoration (Durako and Moffler, 1981; Lewis and Phillips, 1980; Phillips and Lewis, 1983). *Thalassia* appears to have viviporous seeds,

TABLE 1. SEAGRASS PLANTING UNIT TYPES AND AVAILABILITY BY SPECIES.

	Thalassia testudinum	*Halodule wrightii*	*Syringodium filiforme*	*Ruppia maritima*
Plugs	X	X	X	X
Sprigs (drift; excavated)	X	X	X	X
Sprigs (stoloniferous)[a]		X	X	
Seeds				X
Seedlings[b]	X			
Cultivated	X	X		

[a]available currently only from the Florida Keys
[b]available currently only from south Florida

produce cultivated peat-pot-grown seagrass planting units (Phillips and Lewis, 1983). Figure 2 diagrams the design of the culture units and Figure 3 is a photograph of a culture system undergoing testing. Figures 4 and 5 show typical cultivated *Thalassia* planting units, grown from seedlings. Figure 6 shows a typical cultivated *Thalassia* unit after 9 months at a test planting site in the Florida Keys. The raft culture system has been awarded U.S. Patent No. 4,487,588. The success of cultivated planting units has not been tested on a large scale in field situations.

ANCHORING AND WAVE PROTECTION

Many methods have been utilized in attempts to anchor or protect planting units and prevent their removal by wave action or currents. Phillips (1982) reports that bricks, wire mesh, nails, pipes, construction rod, biodegradable mesh paper, and plastic anchors have been tried. Two of the more successful anchoring methods are shown in Figures 1 and 7: Figure 1 shows the method of Derrenbacker and Lewis (1983), commercially available metal erosion control cloth staples used to anchor sprigs of *H. wrightii*; Figure 7 shows the method of Fonseca et al. (1985a), a bent coat hanger used to anchor a clump of bare root seagrass planting material. Both methods have been used successfully in establishing seagrass meadows in unvegetated sites with current velocities up to 20 cm/sec.

Failures of planting units tied to nails and uncoated rebar have been reported by Mangrove Systems, Inc. (1985a, b) and Connell Associates, Inc. (1983). The area of direct seagrass/metal contact should be minimized because the oxidation

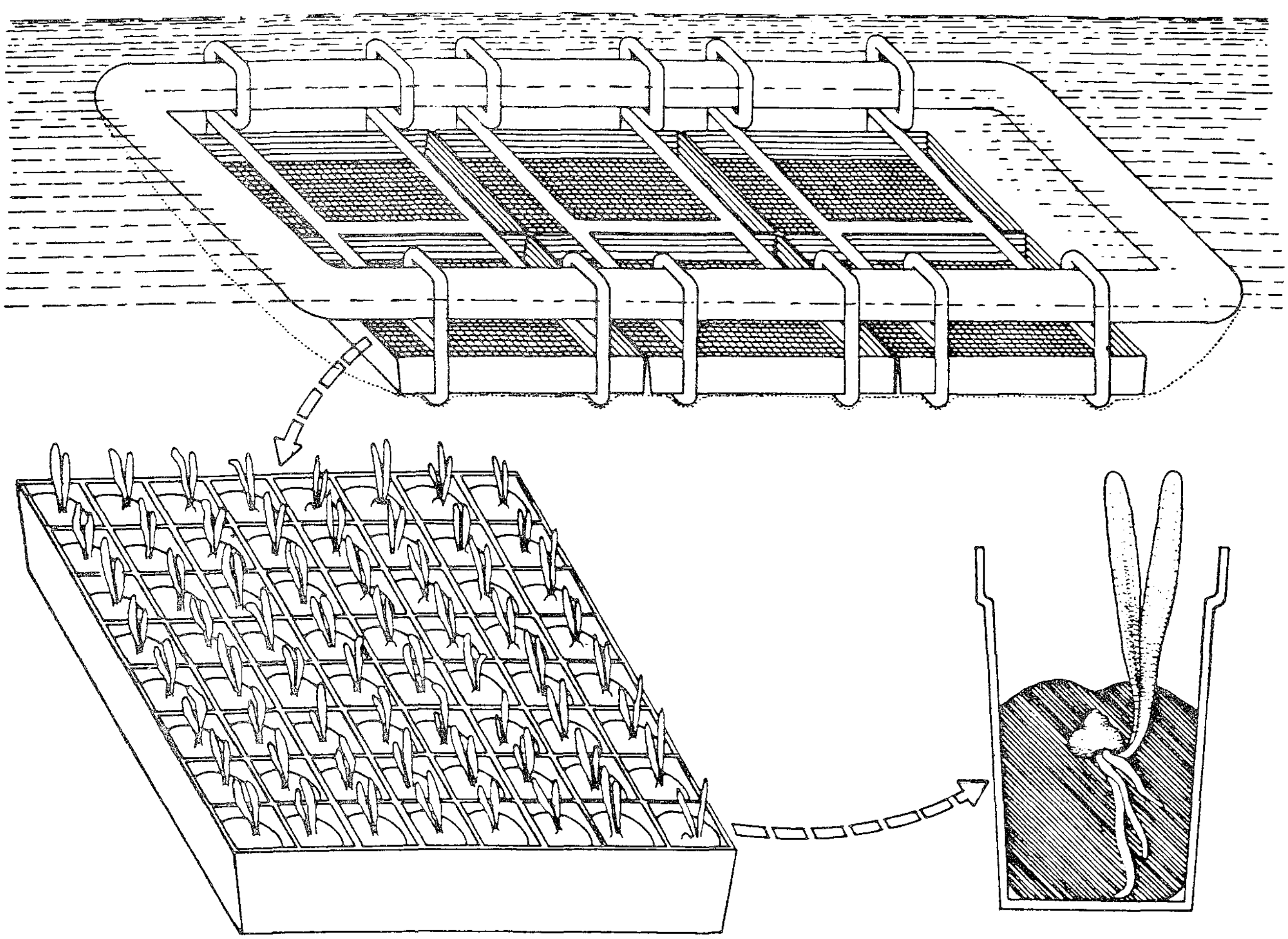

Figure 2. Diagram of seagrass culture raft system developed by Mangrove Systems, Inc., Tampa. (U.S. Patent #4,487,588).

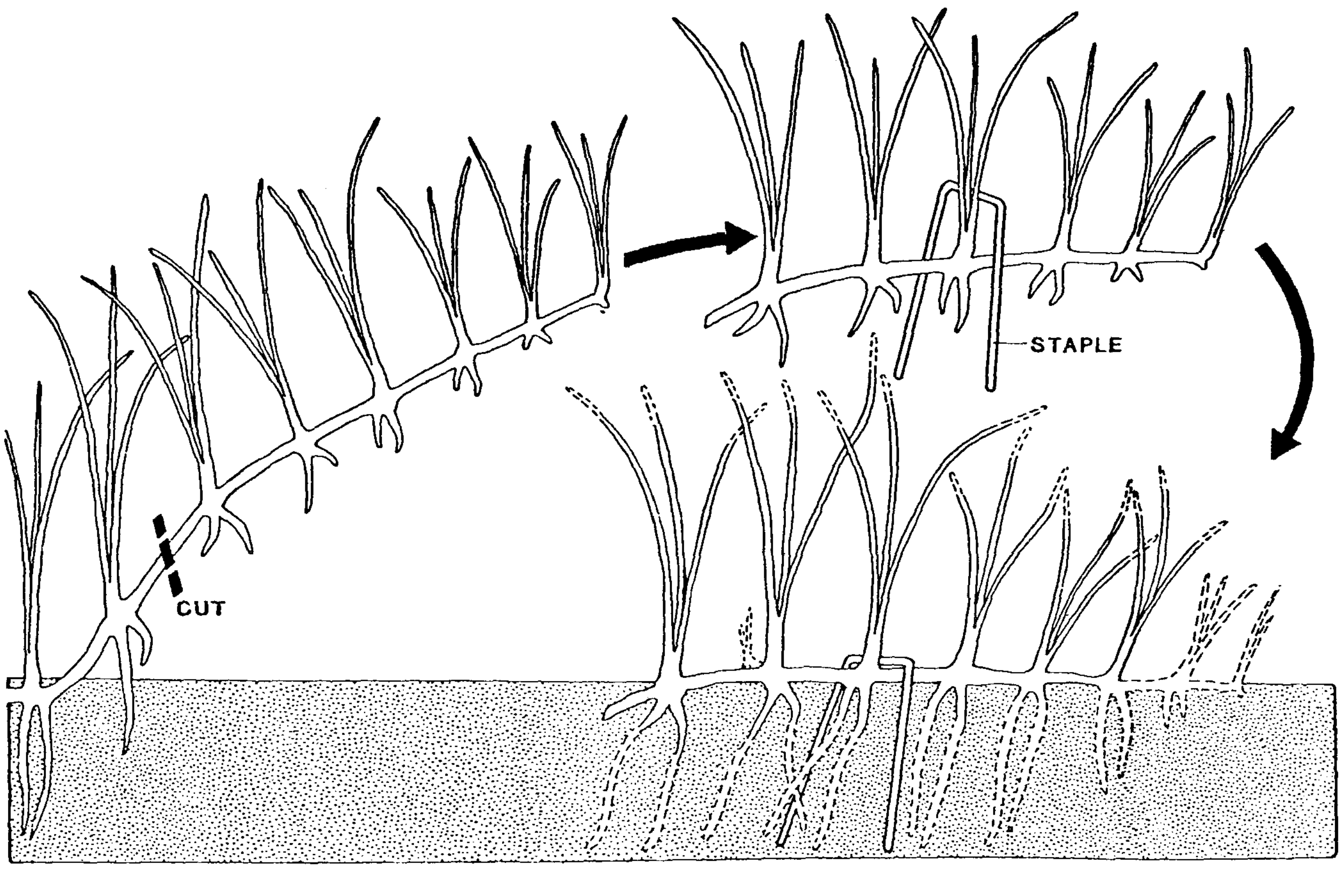

Figure 1. *Halodule* sprig planting method, using erosion control staples (from Derrenbacker and Lewis, 1983).

with germination occurring prior to fruit dehiscence; hence, the term seedling is more appropriate for this material (Moffler and Durako, personal communication). McMillan (1981) has collected and successfully germinated seeds of *Halodule* and *Syringodium* from the Florida Keys, but quantities found to date are too small to be utilized in any large-scale projects. Large quantities of *Thalassia* seedlings are available in south Florida on a seasonal basis (Lewis and Phillips, 1980).

Direct seeding with *Thalassia* seedlings has been attempted experimentally (Thorhaug, 1974; Lewis and Phillips, 1981a, b) and in actual restorations, following the initial establishment of *Halodule* (Derrenbacker and Lewis, 1983). Direct planting of collected seedlings has been attempted on a large scale in Biscayne Bay (Gaby and Langley, 1985) and the Florida Keys (Lewis et al., 1982) with little success. No reports of the intentional collection and planting of *Ruppia* seeds for habitat restoration are known.

CULTIVATED PLANTS

Thorhaug (1974) first described the cultivation of *Thalassia* seedlings from fruits collected in the Bahamas. Fungal infections prevented their use in actual restoration. Durako and Moffler (1981) grew field-collected seedlings of this same species in peat pellets under controlled laboratory conditions. After 3 months in culture, these seedlings were planted in Boca Ciega Bay.

Durako and Moffler (1981) theorized that "if a suitable anchoring method were available for use with seedlings, a non-destructive revegetation program might be developed," which would curtail the prevailing destructive removal of plugs from healthy seagrass beds. They suggested that cultivated *Thalassia* seedlings in peat pellets would have greater anchoring ability than bare root seedlings.

Based on this preliminary work, an experimental open-water-raft culture system was developed to

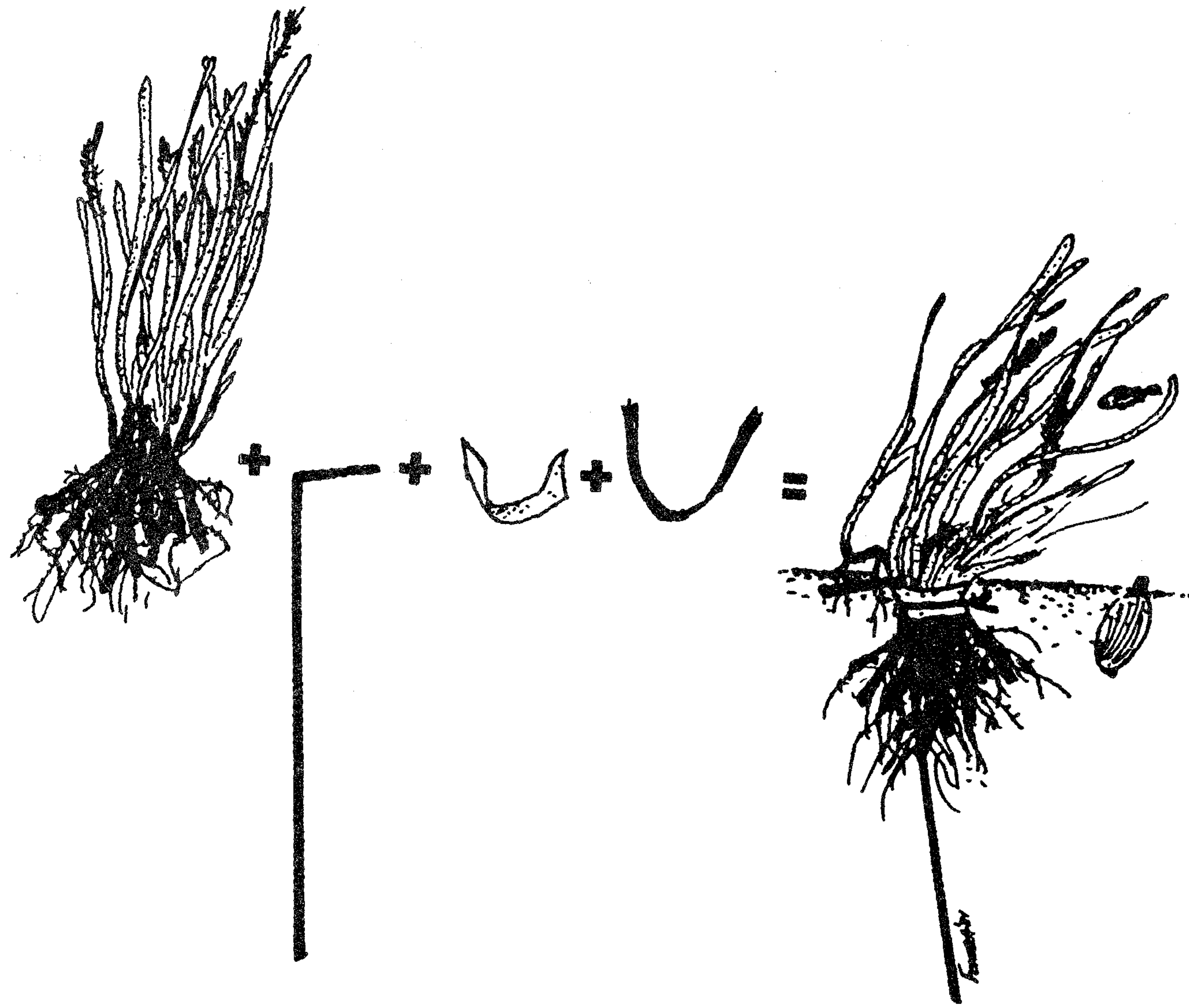

Figure 7. Planting method using bent coat hangers as anchors, from Fonseca et al., 1985.

CASE STUDIES

The following four seagrass restoration or creation projects, completed in the southeast within the past 14 years, were selected from 13 projects (Table 2) that constitute the majority of recent, not exclusively experimental, seagrass plantings. Readers are referred to Phillips (1982) for a summary of previous experimental work. These four case studies were chosen to illustrate successful methodologies, as well as pitfalls that should be avoided.

CASE STUDY 1, CRAIG KEY

Between 1979 and 1983, the replacement of 37 bridges in the Florida Keys required extensive government review before permits for dredge and fill activities were issued. Those permits called for an experimental seagrass planting to determine the feasibility and best methodology of seagrass restoration following construction of the bridges.

The test planting site was located on the

TABLE 2. SELECTED RECENT SEAGRASS PLANTING PROJECTS.
PU = planting units; *H* = *Halodule wrightii*; *T* = *Thalassia testudinum*; *S* = *Syringodium filiforme*.

Location	Size	Species	Year Planted	Reference
Pascagoula River, Mississippi	n/a (135 PU)	*H, T, S*	1972	Eleuterius, 1975, 1976
Horn Island, Mississippi	n/a (2,143 PU)	*H, T, S*	1972-73	Eleuterius, 1975, 1976; Eleuterius and Gill, 1981
Biloxi Bay, Mississippi	n/a (55 PU)	*H, T, S*	1973	Eleuterius, 1975
Turkey Point, Florida	1,800 m^2	*T*	1973	Thorhaug, 1974
Escambia Bay, Florida	n/a (400 PU)	*H*	1974	Rogers and Bisterfeld, 1975
Port St. Joe, Florida	6,912 m^2 (1,488 PU)	*H*	1976	Phillips et al., 1978
Craig Key, Florida	0.4 ha	*H, T, S*	1979	Lewis and Phillips, 1981a, b; Lewis et al., 1982
Lake Surprise, Florida	2.0 ha	*H, T*	1981	Derrenbacker and Lewis, 1983
Biscayne Bay, Florida	49.1 ha	*H, T, S*	1981-85	Post, Buckley, Schuh & Jernigan, 1980; U.S. Army Engineer District, 1980; Metropolitan Dade County, 1981; Thorhaug, 1982; Connell Associates, 1983; Thorhaug, 1985; Gaby and Langley, 1985; Gaby et al., 1986
Florida Keys, Florida	19.8 ha	*H*	1983	Mangrove Systems, Inc., 1985a
Sarasota, Florida	0.2 ha	*H, T*	1983	Mangrove Systems, Inc., 1985b
Florida Keys, Florida	various plots	*H, T, S*	1983	Fonseca et al., unpub.; Fonseca et al., 1987
Northeast Gulf of Mexico, Florida	various plots	*H, S*	1984	Fonseca et al., unpub.; Fonseca et al., 1987

southeast side of Craig Key, Monroe County, Florida (Figures 8 and 9), in a 1.6-ha borrow area that had silted in with fine calcareous sand and silt since its creation during dredging activities approximately 35 years earlier. 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, 1981a).

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.

Plugs consisted of intact sediments and plant material approximately 22 cm x 22 cm x 10 cm high (Figure 10). Sprigs consisted of individual plants

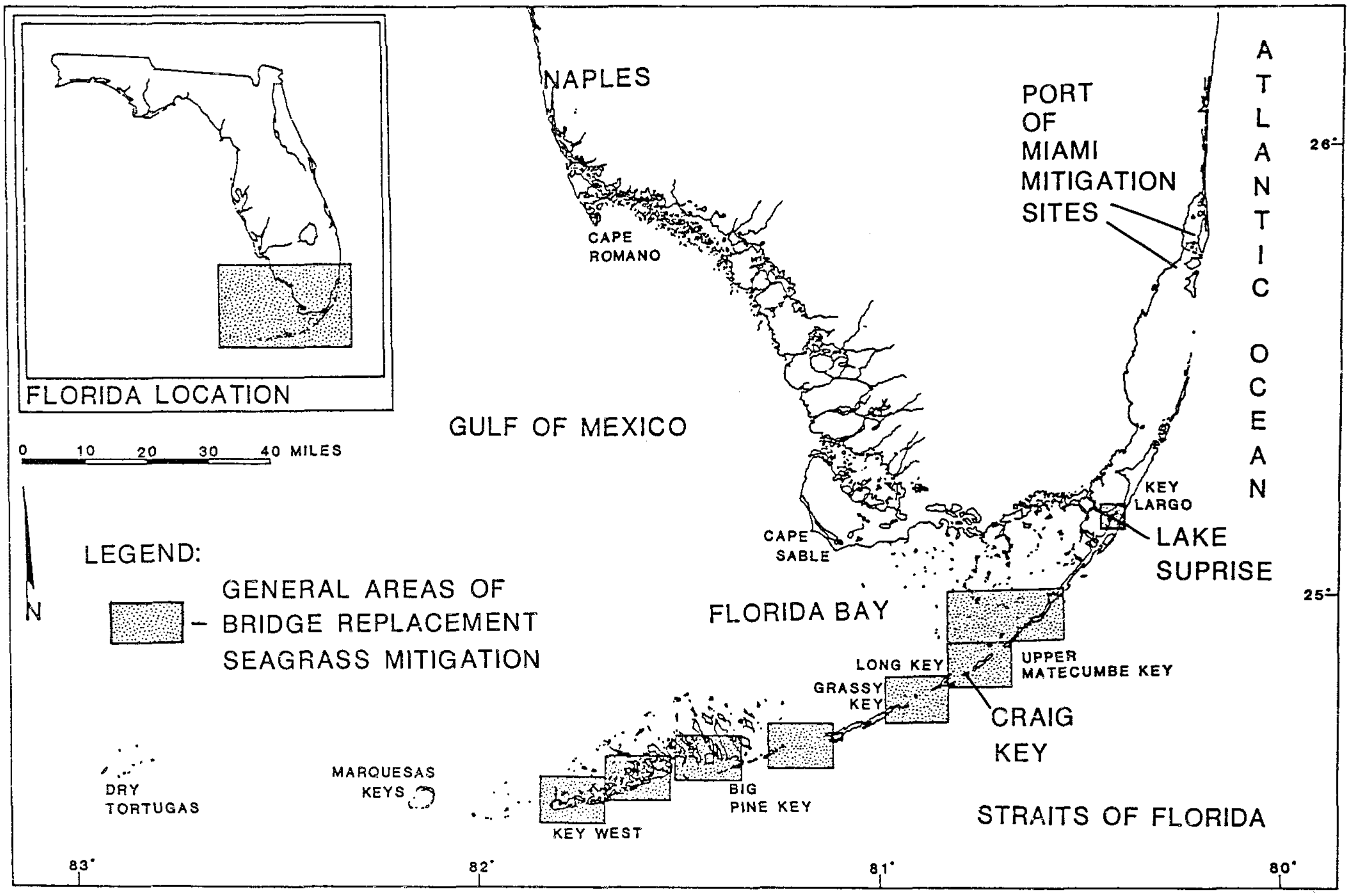

Figure 8. Map showing locations of Lake Surprise, Craig Key, Port of Miami, and Keys Bridge Replacement seagrass planting areas.

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.

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 connecting 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. 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 et al., 1982). An additional year of data was collected by the author and is presented in Table 3.

In all instances, plug material showed greater survival than sprigs, regardless of spacing. 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 the other species, the observed spread of both *H. wrightii* and *S. filiforme* was greater than that of *T. testudinum*. Coalescence

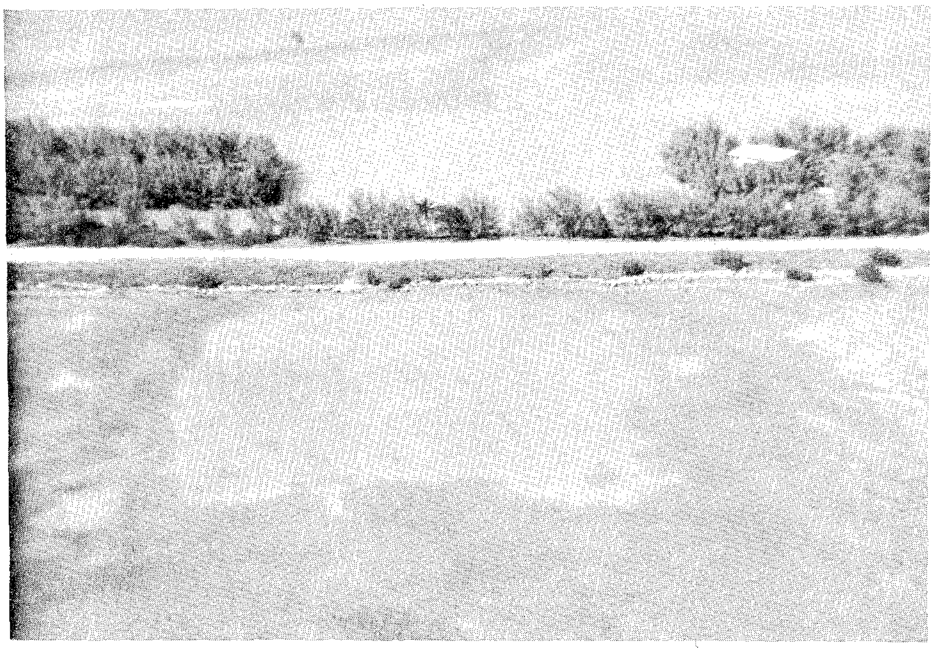

Figure 9. Aerial photograph of the Craig Key planting area, 1979.

(meeting of spreading rhizomes from adjacent planting units) occurred in *Halodule* plots within 6 months, and in *Syringodium* plots within 1 year, but not in the *Thalassia* plug plots until 18 months after planting (Figure 10).

Of the 18 planting/methodology combinations tested, only three proved successful. 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%), but coalescence had occurred by 12 months after planting. Bioturbation by large, burrowing callianassid shrimp was possibly a major factor limiting seagrass survival. Thorhaug (1982) 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* mound density produced a dramatic deterioration of *Thalassia* within 2-4 months."

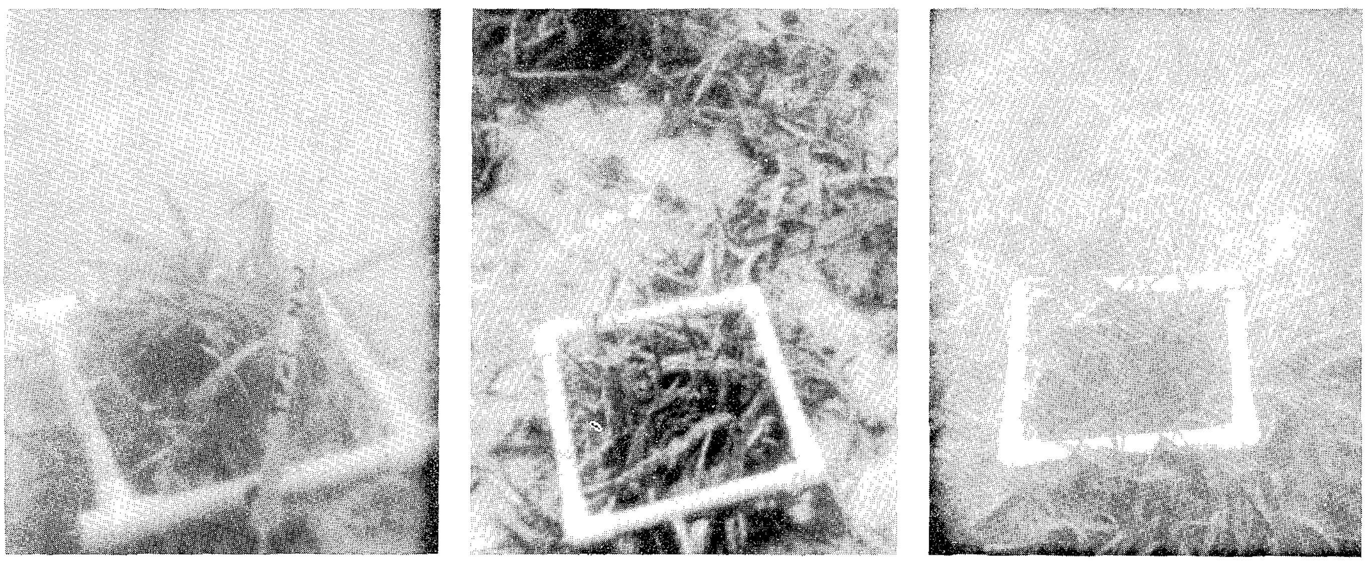

Figure 10. *Thalassia* plug installation and growth at Craig Key over a period of 39 months. PVC quadrat is 22 cm x 22 cm. A - February 1979; B - August 1980; C - May 1982.

early 1981, resulted in the destruction of approximately 2 ha 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: a "moderately" impacted area, located along either side of a "severly" 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 in depth; the other consisted of limestone rubble of various sizes.

These methods of seagrass planting were evaluated in this area:

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 1.35-ha planting area (36,700 planting units);

2) 50,000 *T. testudinum* seedlings were hand-broadcast over an approximately 0.44-ha area for about 0.3-m center coverage;

3) 300 sections of *Thalassia* rhizomes with attached short-shoots were transplanted over 0.19 ha on approximately 0.3-m centers.

Total labor requirements were 370 man hours per hectare (mh/ha) for *Halodule*, 247 mh/ha for *Thalassia* seedlings, and 129 mh/ha for *Thalassia* rhizomes with short-shoots.

Planting occurred in three types of areas:

1) *Halodule wrightii* was planted in a moderately impacted shell hash area, a severely impacted fine silt area, and a severely impacted rocky area.

2) *Thalassia* seedlings were broadcast over moderately impacted areas.

3) *Thalassia* rhizomes with short-shoots were planted in a severely impacted fine silt area.

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

CASE STUDY 3, PORT OF MIAMI

This seagrass mitigation plan was developed to offset the impact of the expansion of the Port of Miami (Figure 8). The expansion program involved the dredging or filling of a total of 103.9 ha of Biscayne Bay, which included 2.2 ha of *T. testudinum*, 2.3 ha of mangrove, 9.8 ha of *Halophila engelmannii*, 21.1 ha of *H. wrightii*, and 68.6 ha of unvegetated shallow bay bottom less than 2 m deep (Post, Buckley, Schuh and Jernigan, Inc., 1980; U.S. Army Engineer District, 1980). The proposed mitigation plan called for replacing the lost seagrass and shallow bay bottom by planting a total of 101.6 ha of seagrass (mixed plantings) at 9 sites ranging in size from 1 to 65.6 ha (Figure 29, U.S. Army Engineer District, 1980).

The seagrass mitigation plan outline (U.S. Army Engineer District, 1980) classifies the 9 sites as 8 "potential planting sites, depending on test plot results," and 1 large-scale (16.2-ha) immediate planting site (#22); apparently no problems were anticipated in planting at this latter site. In reference to site #22, the document states (p. 16), "The design of the basic 6-foot [2-m] interval of mitigating *Halodule* plugs has been suggested by the National Marine Fisheries Service. It calls for installing seagrasses in barren sites at wide intervals to eventually form a seagrass cover over a maximum amount of now-barren, submerged area in order to maximize the fisheries and food web potential." Metropolitan Dade County's (1981) specifications described 15 0.4-ha test plots and one 16.2-ha "permanent planting" at site #22.

Phase I of the planting occurred between December 1981 and November 1982, and consisted of a 10.1-ha, large-scale planting near site #22 (Mercy Hospital), and 13 0.4-ha, test-site plantings, some of which were not completely planted. Thorhaug (1985) described these test plantings as covering 4.2 ha, but, in that same paper, she did not mention the 10.1-ha planting, possibly due to the

TABLE 3. CRAIG KEY PLANTING UNIT SURVIVAL.

Plot	Units, spacing	Number Planted	Number Surviving: 8/79	2/80	8/80	2/81	2/82
TP-1	*Thalassia* plugs, 1-m	49	49	48	48	48	48
TT-1	*Thalassia* sprigs, 1-m	49	19	5	0	0	0
HP-1	*Halodule* plugs, 1-m	49	33	0	0	0	0
HT-1	*Halodule* sprigs, 1-m	49	14	1	1	0	0
SP-1	*Syringodium* plugs, 1-m	49	30	35%[1]	75%	75%	75%
ST-1	*Syringodium* sprigs, 1-m	49	49	14	0	0	0
TP-2	*Thalassia* plugs, 2-m	49	39	37	48	44	44
TT-2	*Thalassia* sprigs, 2-m	49	9	0	2	0	0
HP-2	*Halodule* plugs, 2-m	49	24	0	5	0	0
HT-2	*Halodule* sprigs, 2-m	49	14	0	0	0	0
SP-2	*Syringodium* plugs, 2-m	49	30	4	25%	0	0
ST-2	*Syringodium* sprigs, 2-m	49	7	3	0	0	0
TS-2[2]	*Thalassia* seedlings, 2-m	49	49	0	1	0	0
TS-1	*Thalassia* seedlings, 1-m	49	49	9	0	3	0
TS-1/3	*Thalassia* seedlings, 1/3-m	49	49	0	0	0	0
TS/H-1	*Thalassia* seedlings among *Halodule*, 1-m	49	49	0	9	9	7
HHP-1[3]	*Halodule* plugs, 1-m	49	—	49	50%[1]	30%	0
HHT-1	*Halodule* sprigs, 1-m	49	—	49	21	2	0

[1]percentages refer to percent cover after coalescence prevented individual counts.
[2]plots TS-1, TS-1/3, and TS/H-1 were planted in August 1979.
[3]plots HHP-1 and HHT-1 were planted in February 1980.

CASE STUDY 2, LAKE SURPRISE

In 1981, the Florida Keys Aqueduct Authority was authorized to place a new, larger 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 8). Subsequent pipeline construction, in low overall survival rate of 8.1% in 8 plots monitored by Connell Associates, Inc. (1983). How the original specifications of 15 test plots and one 16.2-ha permanent planting were changed is not known.

An item that stands out as unusual is the 28% survival of *T. testudinum* seedlings in test plot #45 (Thorhaug, 1985). This was noted as an "author estimate"; however, Connell Associates, Inc. (1983), reported no *Thalassia* seedling installations for that plot.

Thalassia testudinum plugs were not part of the study plan, apparently because the originators of the planting design did not believe they would work (Thorhaug, 1982), in spite of over 90% survival of *Thalassia* plugs transplanted in the Keys (Lewis et al., 1982). The significance of this is that Thorhaug (1985) concluded that "plugs did not do well in general" (p. 60), while stating that "in select locations, *Thalassia* seeds with anchors can be transplanted with high viability and growth" (p. 61). The latter statement is based on data from 3 subplots, including test plot #45, and no acknowledgement is made of the 1.3% survival of *Thalassia* seedlings in the 8 subplots at the 10.1-ha site monitored by Connell Associates, Inc. (1983).

Overall survival for the Phase I plantings was 12% (Connell and Associates, 1983). With two other phases completed, a total of 49.1 ha of seagrass (mostly *Thalassia*) had been transplanted by the summer of 1985. Survival of the largest of the three phases (Phase IIb, 28.3 ha) has recently been reported to be only 10.4% (Eric Hughes, U.S. Environmental Protection Agency, personal communication), and further efforts to achieve the 101.6 ha of restored seagrass have been abandoned due to these low survival rates.

CASE STUDY 4, FLORIDA KEYS BRIDGE REPLACEMENT

The areal extent of seagrass meadows destroyed as a direct result of the replacement of 37 bridges in the Florida Keys totalled 26.6 ha. Essentially all of this area had been vegetated with *T. testudinum*. Of the 26.6 ha total, 12.4 ha were considered not restorable, due to permanent loss through filling, bridge shading, and post-disturbance substrate (e.g., rock bottoms with no available sediment structure) (Mangrove Systems, Inc., 1985a).

The remaining 14.3 ha, distributed over 22 sites (Figure 8, Table 4), were determined to be capable of supporting restoration efforts. Additionally, 6.9 ha (at 3 sites) of restorable seagrass meadows, damaged as a result of activities not related to bridge construction, became available concurrent with the first phase of restoration efforts.

Summary

Total seagrass area lost due to bridge construction	26.6 ha
Non-restorable area	12.4 ha
Original area identified for restoration	14.3 ha
Additional area available for restoration (not related to bridge construction)	6.9 ha
Total area identified for restoration	21.2 ha

The Florida Keys Seagrass Restoration Project was executed in two phases. Phase I occurred during 16-23 April 1983; upon completion, 9.1 ha had been planted over 4 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, 4.4 ha had been planted over 16 sites. 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*. Also, only staples were used as anchoring devices due to low survival rates of units anchored with nails.

Summary

Total area identified for restoration	21.2 ha
Phase I area planted	9.1 ha
Phase II area planted	4.4 ha
Total area planted	14.5 ha
Remaining area (20 Aug 83)	7.7 ha

The combined area planted during both phases totalled 14.5 ha. As of 23 August 1984, a total of 8.3 ha 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 4. SUMMARY OF SEAGRASS PLANTING FOR THE FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION. (TOTAL HECTARES SURVIVING AND PERCENT SURVIVAL AS OF 23 AUGUST 1984)

Site / Area (ha)	Initial Available	Planted, Phase I	Planted, Phase II	Planted, Compensatory	Total Planted	Total Surviving	Percent Survival*
1. Stock Island	6.07	6.88			6.88	6.88	100
2. Boog Powell Marina	0.40		0.40		0.40 (0.89)	0.40	100
3. Shark Channel	0.85	0.61	0.28		0.85	0.00	0
4. Harris Channel	0.19		0.10		0.10	0.16	167
5. North Harris Channel	0.19		0.19		0.19	0.19	100
6. Park Channel	0.16		0.14		0.14	0.00	0
7. Kemp Channel	0.17		0.24		0.24	0.20	83
8. Niles Channel	0.18		0.18		0.18	0.00	0
9. Torch - Ramrod Channel	0.33		0.09		0.04	0.04	100
10. Torch Channel	0.21						
11. Ohio - Bahia Honda Channel	0.31						
12. Missouri - Little Duck	0.08						
13. Seven-Mile Bridge, Site A	1.65						
14. Seven-Mile Bridge, Site B	0.89						
15. Seven-Mile Bridge, Site C	0.38						
16. Seven-Mile Bridge, Site D	1.24		0.57		0.57	0.00	0
17. Seven-Mile Bridge, Site E	0.39	0.12	0.39		0.39	0.00	0
18. Seven-Mile Bridge, Site F	1.45	1.44			1.44	0.00	0
19. Seven-Mile Bridge, Site G	0.21		0.06		0.06	0.00	0
20. Tom's Harbor Channel	2.06						
21. Long Key Channel, West	0.72		0.44		0.44	0.04	10
22. Long Key Channel, East	1.55		0.21		0.21	0.05	25
23. Channel No. 5	0.58		0.58		0.58	0.19	33
24. Craig Key	0.40		0.10		0.10	0.00	0
25. Indian Key Channel	0.55		0.51		0.51 (13.50)	0.10	20
Subtotals (FDER):	21.16	9.06	4.44		13.42	8.27	61.3
26. Sexton Cove	5.67			5.67	5.67	5.67	100
27. Boog Powell	0.08			0.08	0.08 (19.25)	0.08	100
TOTALS:	26.91			5.75	10.08	14.02	72.8

*percent area meeting 80% cover requirement

Summary

Total area planted	14.5 ha
Total area meeting 80% cover criterion	8.3 ha
Total area not surviving	5.2 ha
Percent meeting cover requirements	61.3%

Subsequent to Phases I and II, compensatory planting efforts were undertaken by Mangrove Systems, Inc. At Sexton Cove, 5.6 ha were planted. Planting material consisted of *Halodule wrightii* long-shoots, on approximately 2-m centers, anchored with staples. Additionally, 0.1 ha 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 totalled 5.7 ha.

Summary

Area not surviving	5.2 ha
Area of compensatory planting	5.7 ha

The total area planted during Phase I, Phase II, and the compensatory planting was 19.2 ha. The total surviving area meeting contractural requirements of 80% cover is 14.0 ha; these figures are equivalent to 72.8% success.

Summary

Area planted in Phases I and II	14.5 ha
Area of compensatory planting	5.7 ha
Total area planted	19.2 ha
Area surviving in Phases I and II	8.3 ha
Compensatory area surviving	5.7 ha
Total area surviving	14.0 ha
Percent success (total)	72.8%

An example of a planting area is shown in Figures 11 and 12. Figure 11 shows Site 2 at Boog Powell Marina, Key West, 3 months and 30 months after planting with shoal grass. Figure 12 shows a 24-month time sequence of underwater photographs of the same area. The rapid cover by *H. wrightii* is apparent, as is the volunteer recruitment of *T. testudinum* seedlings into the planted *Halodule*.

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);

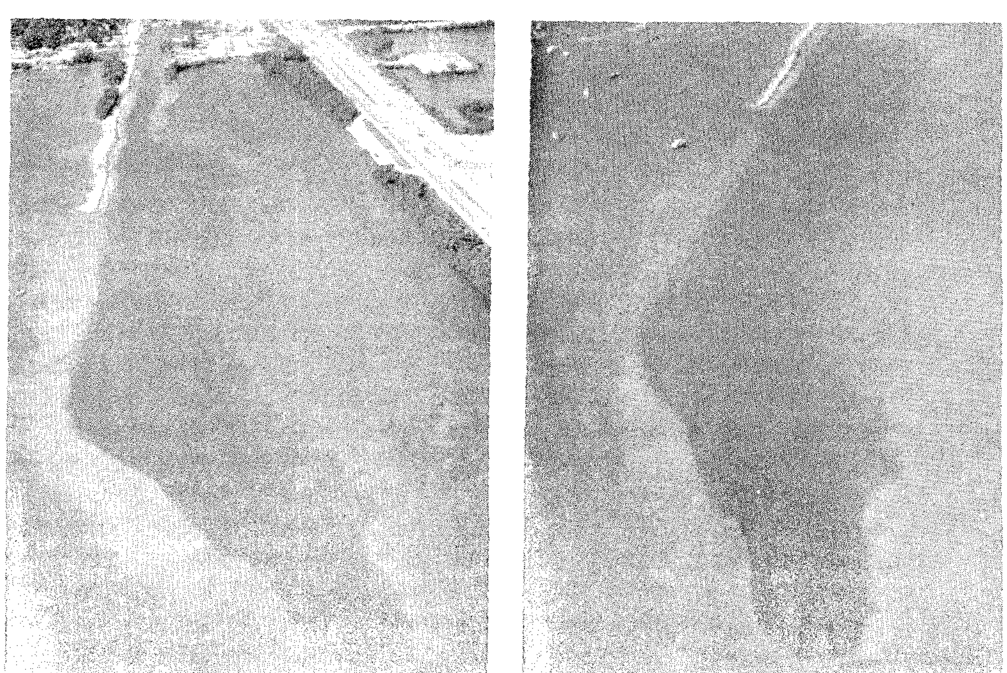

Figure 11. Aerial photographs of Florida Keys planting site 2, Boog Powell Marina. A - 3 months after planting; B - 30 months after planting.

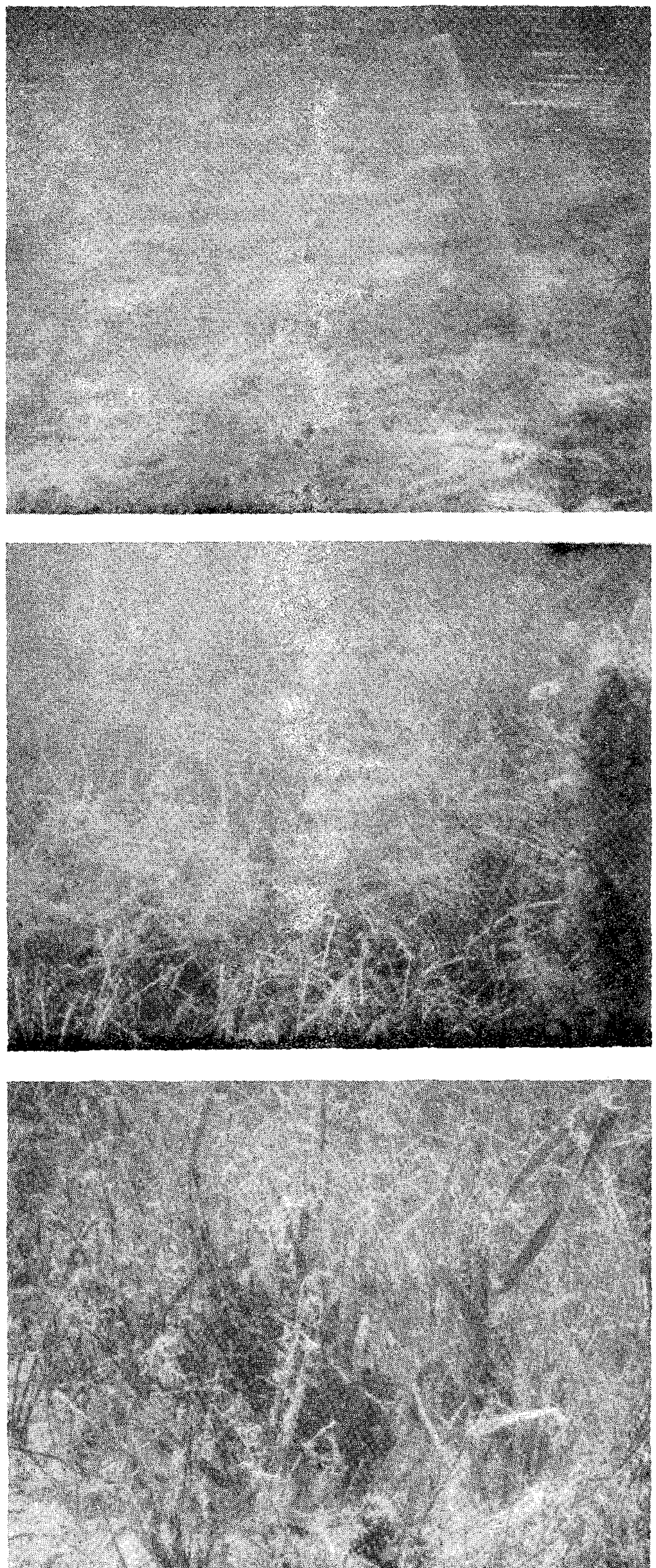

Figure 12. Boog Powell Marina planting site. A - August 1983 (just planted; note corner stake); B - same plot, August 1984; C - August 1985 (same area, but not **same** plot as A and B). Note volunteer turtle grass in planted shoal grass.

2. bioturbation by burrowing animals such as *Callianassa* and surface feeders such as *Limulus* (e.g., Site 24, Craig Key);

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 (1982) were able to achieve some *H. wrightii* survival and growth on rocky substrates in a very low-current area in north Key Largo, but apparently this is not possible in higher-current areas.

Lewis et al. (1982, page 85) observed in an earlier planting at Craig Key that "biogenic reworking of the sediments and grazing by benthic animals such as callianassid shrimp were probably major factors contributing to the failure" of some test plantings. Suchanek's (1983) test plantings had confirmed this when he made the observation (p. 281):

> Maximum seagrass productivity and percent cover are negatively correlated (significant to $p < .01$) with *Callianassa* mound density. Experimental and control transplants of the turtle grass *Thalassia testudinum* into regions of high (16 m^{-2}) and low (1 m^{-2}) *Callianassa* mound density produced a dramatic deterioration of *Thalassia* within 2-4 months in high-density *Callianassa* areas. Ejected sediment either reduces available light for photosynthesis or physically smothers *Thalassia*, thereby eliminating it from regions of abundant *Callianassa*.

Newly disturbed sites, essentially free of *Callianassa* burrows, are probably suitable for restoration for a short time, i.e., until *Callianassa* colonization reaches a given density (approximately 16 burrows m^{-2}), beyond which seagrass restoration attempts will probably prove futile. Thus, early restoration appears critical. Unfortunately, most of the Keys sites were damaged 2-5 years before restoration was begun. Gradual natural revegetation of some of these sites has occurred, apparently through the spread of volunteer *T. testudinum* seedlings, which appear to tolerate disturbance better than vegetative shoots of *H. wrightii*. Collected seedlings or cultivated planting units of *Thalassia* would, therefore, be more likely to survive in such areas.

Finally, human disturbance of sites is largely unpredictable and, consequently, uncontrollable. Steps to prevent disturbance, such as closing the Pigeon Key boat channel, would help, but are probably not politically acceptable. Seeding such areas with *T. testudinum* seedlings could help recovery, but continued human disturbance may limit final plant cover.

These observations suggest that potential planting areas can now be examined with more analytical criteria. Obviously, a suitable site should have a minimum of 60 cm of sediment depth, a low density of *Callianassa* burrows (about 1 m^{-2}), a water depth of less than 2 m, and a minimum of recreational use and boat traffic, and be in a low-current area. We have also observed that the presence of volunteer seagrass sprigs or seedlings is a good indication of suitability, and that some sites will revegetate without planting, at least to an early successional stage (*H. wrightii*).

CONCLUSIONS AND RECOMMENDATIONS

What have we learned from the past decade of intense efforts to restore seagrasses? Five major conclusions and recommendations are apparent.

1. The field is changing rapidly and anyone attempting to restore seagrasses should first consult the most current scientific publications. Unfortunately, much of the data is unpublished and, therefore, hard to get. Conflicting conclusions and recommendations are common, but the data show clear trends of success with some methods (e.g., plugs of *Thalassia*) and failure with others (e.g., bare-root *Thalassia* seedlings). In spite of this, clearly unsuccessful methods are still described as successful [e.g., "*Thalassia* seeds with anchors can be transplanted with high viability and growth..." (Thorhaug, 1985, p. 61)]. Examine the data carefully and talk to several "experts."

2. Salvage of seagrass plant material from sites proposed for destruction should be given higher priority. Van Breedveld (1975) first demonstrated that intact plugs of *Thalassia*, *Syringodium*, and *Halodule* could be successfully moved. Concern about damage to undisturbed seagrass meadows used as donor sites has been expressed by Darovec et al. (1975) and Phillips and Lewis (1983). Few data are available to document that recovery of donor sites and salvage of seagrasses are significant sources of seagrass planting material, although such sources are presently very limited.

3. The excavation of seagrass transplant material from healthy donor areas not scheduled for destruction should be discouraged until recovery data confirm the usefulness of this technique.

4. The use of seagrass population growth models, up-front mitigation where feasible, and more rigorous compliance monitoring are essential components of any seagrass restoration program (see Fonseca et al., 1987).

5. Future restoration efforts will require large amounts of plant material, and strong consideration should be given to further development of non-

TABLE 5. SUMMARY OF EXISTING AND PROPOSED SEAGRASS RESTORATION PLANT MATERIAL SOURCES.

Source	Advantages	Disadvantages
A. Harvested, unattached rhizomes	- available year-round - culture not required	- presently available for *Halodule wrightii* and *Syringodium filiforme* only, in the Florida Keys
B. Harvested fruits	- no sediment disturbance	- seasonal availability - locating fruiting plants - high cost of collection - presently available only for *Thalassia*
C. Collected seedlings	- no sediment disturbance - salvage of plant material that would normally die - low collection costs	- seasonal availability - presently available only for *Thalassia* - culture may be required
D. Beach drift-line salvage	- available year-round - salvage of plant material that would normally die - no sediment disturbance - low collection costs	- culture may be required
E. Impact site salvage	- intact plug removal helps ensure success	- replanting site needs to be prepared prior to salvage

destructive plant material sources, such as planting unit cultures (see Table 5).

LITERATURE CITED

BELL, F. W., P. E. SORENSEN,
and V. R. LEEWORTHY
1982. The economic impact and valuation of saltwater recreational fisheries in Florida. Florida Sea Grant College. Rep. No. 47. Gainesville, Florida.

BETHEL, J. P.
1961. Webster's New Collegiate Dictionary. The Riverside Press, Cambridge, Massachusetts. 1174 pp.

CONNELL ASSOCIATES, INC.
1983. Port of Miami seagrass restoration project — Task 8 final report Phase I survival. 41 pp. + apps.

DAROVEC, J. E., J. M. CARLTON,
T. R. PULVER, M. D. MOFFLER, G. B. SMITH,
W. K. WHITFIELD, S. A. WILLIS,
K. A. STEIDINGER, and E. A. JOYCE
1975. Techniques for coastal restoration and fishery enhancement in Florida. Fla. Mar. Res. Publ. No. 15. Fla. Dept. Nat. Resour. Bur. Mar. Res. St. Petersburg, Florida.

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, Florida.

DURAKO, M. J., and M. D. MOFFLER
1981. Variation in *Thalassia testudinum* seedling growth related to geographic origin. Pp. 100-117 *in* R. H. Stovall, ed. Proc. 8th Ann. Conf. Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Florida.
1984. Qualitative assessment of five artificial growth media on growth and survival of *Thalassia testudinum* (Hydrocharitaceae) seedlings. Pp. 73-92 *in* F. J. Webb, ed. Proc. 11th Ann. Conf. Wetland Restoration and Creation. Hillsborough Community College, Tampa, Florida.

ELEUTERIUS, L. N.
1975. Submergent vegetation for bottom stabilization. Pp. 439-456 *in* L. E. Cronin, ed. Estuarine research, Vol. III Geology and Engineering. Academic Press, New York.
1976. Transplanting maritime plants to dredged material in Mississippi waters. Pp. 900-918 *in* Proc. Symposium on Dredging and its Environmental Effects. American Society of Civil Engineers. Mobile, Alabama.

ELEUTERIUS, L. N., and J. I. GILL, JR.
1981. Long-term observations on seagrass beds and saltmarsh established from transplants. Pp. 74-86 *in* R. H. Stovall, ed. Proc. 8th Ann. Conf. Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Florida.

ELEUTERIUS, L. N., and G. J. MILLER
1976. Observations on seagrasses and seaweeds in Mississippi Sound since Hurricane Camile. J. Miss. Acad. Sci. 21: 58-63.

FONSECA, M. S., W. J. KENWORTHY,
and G. W. THAYER
1984. Transplanting guidelines for seagrasses in coastal and adjacent waters of the United States. Southeast Fisheries Center, Beaufort Laboratory, National Marine Fisheries Service. Draft final report.

FONSECA, M. S., W. J. KENWORTHY,
K. M. CHEAP, C. A. CURRIN,
and G. W. THAYER
1985a. A low cost transplanting technique for shoal grass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*). Instruction Report EL-84-1. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 16 pp.

FONSECA, M. S., W. J. KENWORTHY,
G. W. THAYER, D. Y. HELLER,
and K. M. CHEAP
1985b. Transplanting of the seagrasses *Zostera marina* and *Halodule wrightii* for sediment stabilization and habitat development on the East Coast of the United States. Tech. Rep. EL-85-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 49 pp. + tables.

FONSECA, M. S., G. W. THAYER,
and W. J. KENWORTHY
1987. The use of ecological data in the implementation and management of seagrass restoration. Pp. 175-188 *in* M. J. Durako, R. C. Phillips, and R. R. Lewis, eds. Proceedings of the Symposium on Subtropi-

cal-Tropical Seagrasses of the Southeastern United States. Fla. Mar. Res. Publ. No. 42. Fla. Dept. Nat. Resour. Bur. Mar. Res. St. Petersburg, Florida. 209 pp.

GABY, R., and S. LANGLEY
1985. Seagrass mitigation in Biscayne Bay, Florida. Pp. 904-919 *in* O. T. Magoon et al., eds. Coastal Zone '85, Vol. 1. American Society of Civil Engineers. New York.

GABY, R., S. LANGLEY, and R. F. KEOUGH
1986. Port of Miami seagrass restoration: analysis of management and economics of a large scale dredge mitigation project. Pp. 550-561 *in* Proc. XI World Dredging Congress. CEDA. Delft, The Netherlands.

GILMORE, R. G., C. J. DONOHOE, and D. W. COOKE
1983. Observations on the distribution and biology of east-central Florida populations of the common snook, *Centropomus undecimalis* (Bloch). Fla. Scientist 46: 313-336.

HARLEM, P. W.
1979. Aerial photographic interpretation of the historical changes in northern Biscayne Bay, Florida: 1925 to 1976. University of Miami, Sea Grant Tech. Bull. 40. Coral Gables, Florida.

HARRIS, B. A., K. D. HADDAD, K. A. STEIDINGER, J. A. HUFF, and M. Y. HEDGEPETH
1983. Assessment of fisheries habitat: Charlotte Harbor and Lake Worth, Florida. Fla. Dept. Nat. Resour. Bur. Mar. Res. St. Petersburg, Florida.

HARTMAN, D. S.
1979. Ecology and behavior of the manatee (*Trichechus manatus*) in Florida. Special Publication No. 5, Amer. Soc. Mammalogists.

HOFFMAN, W. E., M. J. DURAKO, and R. R. LEWIS
1985. Habitat restoration in Tampa Bay. Pp. 636-657 *in* S. F. Treat, J. L. Simon, R. R. Lewis, and R. L. Whitman, Jr., eds. Proc. Tampa Bay Area Scientific Information Symposium (May 1982). Burgess Publishing Co. Minneapolis, Minnesota. 663 pp.

KRUCZYNSKI, W. L.
1982. Salt marshes of the northeastern Gulf of Mexico. Pp. 71-87 *in* R. R. Lewis, ed. Creation and restoration of coastal plant communities. CRC Press. Boca Raton, Florida. 219 pp.

LEWIS, R. R.
1977. Impacts of dredging in the Tampa Bay estuary, 1876-1976. Pp. 31-55 *in* E. L. Pruitt, ed. Proc. 2nd Ann. Conf. of the Coastal Society—Time-stressed environments: assessments and future actions. Coastal Society, Arlington, Virginia.
1982a. ed. Creation and restoration of coastal plant communities. CRC Press. Boca Raton, Florida. 219 pp.
1982b. Low marshes, peninsular Florida. Ch. 7, pp. 147-152 *in* R. R. Lewis, ed. Creation and restoration of coastal plant communities. CRC Press. Boca Raton, Florida. 219 pp.
1982c. Mangrove forests. Ch. 8, pp. 154-171 *in* R. R. Lewis, ed. Creation and restoration of coastal plant communities. CRC Press. Boca Raton, Florida. 219 pp.

LEWIS, R. R., M. J. DURAKO, M. D. MOFFLER, and R. C. PHILLIPS
1985a. Seagrass meadows of Tampa Bay: a review. Pp. 210-246 *in* S. F. Treat, J. L. Simon, R. R. Lewis, and R. L. Whitman, Jr., eds. Proc. Tampa Bay Area Scientific Information Symposium [May 1982]. Burgess Publishing Co. Minneapolis, Minnesota. 663 pp.

LEWIS, R. R., R. G. GILMORE, D. W. CREWZ, and W. E. ODUM
1985b. The fishery resources of mangrove forests. Pp. 281-336 *in* W. Seaman, Jr., ed. Florida Aquatic Habitat and Fishery Resources. American Fisheries Society, Florida Chapter. Kissimmee, Florida. 543 pp.

LEWIS, R. R., and R. C. PHILLIPS
1980. Occurrence of seeds and seedlings of *Thalassia testudinum* Banks ex König in the Florida Keys (U.S.A.). Aquat. Bot. 9: 377-380.
1981a. 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.

1981b. Experimental seagrass mitigation in the Florida Keys. Pp. 155-173 *in* D. P. Cole, ed. Proc. 7th Ann. Conf. on Restoration and Creation of Wetlands. Hillsborough Community College, Tampa, Florida. 294 pp.

LEWIS, R. R., R. C. PHILLIPS, D. J. ADAMEK, and J. C. CATO

1982. Final report — seagrass revegetation studies in Monroe County. Florida Dept. of Transportation. Tallahassee, Florida. 95 pp. + apps.

MANGROVE SYSTEMS, INC.

1985a. Combined final report — Florida Keys seagrass restoration project. Report to the Florida Dept. of Environmental Regulation, Tallahassee, Florida. 73 pp.

1985b. Combined report — one-year and 21 months post-transplant monitoring, New Pass bridge (Sarasota) seagrass planting. Report to C-Way Enterprises, Inc. Tampa, Florida. 22 pp.

MCMILLAN, C.

1981. Seed reserves and seed germination for two seagrasses, *Halodule wrightii* and *Syringodium filiforme*, from the western Atlantic. Aquat. Bot. 11: 279-296.

METROPOLITAN DADE COUNTY, PUBLIC WORKS DEPT.

1981. Specifications for monitoring of seagrass planting and survival for the Port of Miami seagrass mitigation plan. var. paging.

PHILLIPS, R. C.

1960. Observations on the ecology and distribution of the Florida seagrasses. Prof. Pap. Ser. No. 2. Fla. St. Bd. Conserv., Mar. Res. Lab. St. Petersburg, Florida. 72 pp.

1982. Seagrass meadows. Ch. 9, pp. 173-201 *in* R. R. Lewis, ed. Creation and restoration of coastal plant communities. CRC Press, Inc. Boca Raton, Florida. 219 pp.

PHILLIPS, R. C., and R. R. LEWIS

1983. Influence of environmental gradients on variations in leaf widths and transplant success in North American seagrasses. J. Mar. Tech. Soc. 17: 59-68.

PHILLIPS, R. C., M. K. VINCENT, and R. T. HUFFMAN

1978. Habitat development field investigations, Port St. Joe — Seagrass demonstration site, Port St. Joe, Florida. Tech. Rep. D-78-33, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 37 pp. + app.

POST, BUCKLEY, SCHUH & JERNIGAN, INC.

1980. Final mitigation plan for mangroves and seagrasses — Port of Miami. Metropolitan Dade County Seaport Dept. var. paging.

RANWELL, D. S., D. W. WYER, L. A. BOORMAN, J. M. PIZZEY, and R. J. WATERS

1974. *Zostera* transplants in Norfolk and Suffolk, Great Britain. Aquaculture 4: 185-198.

ROGERS, R. G., and F. T. BISTERFELD

1975. Seagrass vegetation attempts in Escambia Bay, Florida, during 1974. Pp. 28-34 *in* R. R. Lewis, ed. Proc. 2nd Ann. Conf. on Restoration of Coastal Vegetation in Florida. Hillsborough Community College, Tampa, Florida.

SUCHANEK, T. H.

1983. Control of seagrass communities and sediment distribution by *Callianassa* (Crustacea, Thalassinidea) bioturbation. J. Mar. Res. 41: 281-298.

TABB, D. C., and R. B. MANNING

1961. A checklist of the flora and fauna of northern Florida Bay and adjacent brackish water of the Florida mainland collected during the period July 1957 through September 1960. Bull. Mar. Sci. 11: 552-649.

TAYLOR, J. L., and C. H. SALOMAN

1968. Some effects of hydraulic dredging and coastal development in Boca Ciega Bay, Florida. U.S. Fish & Wildlife Service, Fish. Bull. 67: 213-241.

THAYER, G. W., H. H. STUART, W. J. KENWORTHY, J. F. USTACH, and A. B. HALL

1979. Habitat values of salt marshes, mangroves, and seagrasses for aquatic organisms. Pp. 235-247 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland functions and values: the stage of our understanding. American Water Resources Association. Minneapolis, Minnesota.

THORHAUG, A.

1974. Transplantation of the seagrass *Thalassia testudinum* König. Aquaculture 4: 177-183.

1982. Final report on seagrass mitigation of 25 acres of combined *Thalassia - Halodule* at three foot centers and 13 test sites.

1985. Large-scale seagrass restoration in a damaged estuary. Mar. Poll. Bull. 16: 55-61.

THORHAUG, A., and C. B. AUSTIN

1976. Restoration of seagrasses with economic analysis. Environ. Conserv. 3: 259-267.

U.S. ARMY ENGINEER DISTRICT, JACKSONVILLE

1980. Final environmental impact statement, port expansion program, Biscayne Bay, Dade County, Florida. 52 pp. + apps.

VAN BREEDVELD, J.

1975. Transplanting of seagrasses with emphasis on the importance of substrate. Fla. Mar. Res. Publ., Fla. Dept. Nat. Resour. Bur. Mar. Res. 17:26.

ZIEMAN, J. C.

1982. The ecology of the seagrasses of south Florida: a community profile. U.S. Fish & Wildlife Service, Office of Biological Services. FWS/OBS-82/25. Washington, D.C. 158 pp.