A GUIDE TO PLANTING SEAGRASSES IN THE GULF OF MEXICO

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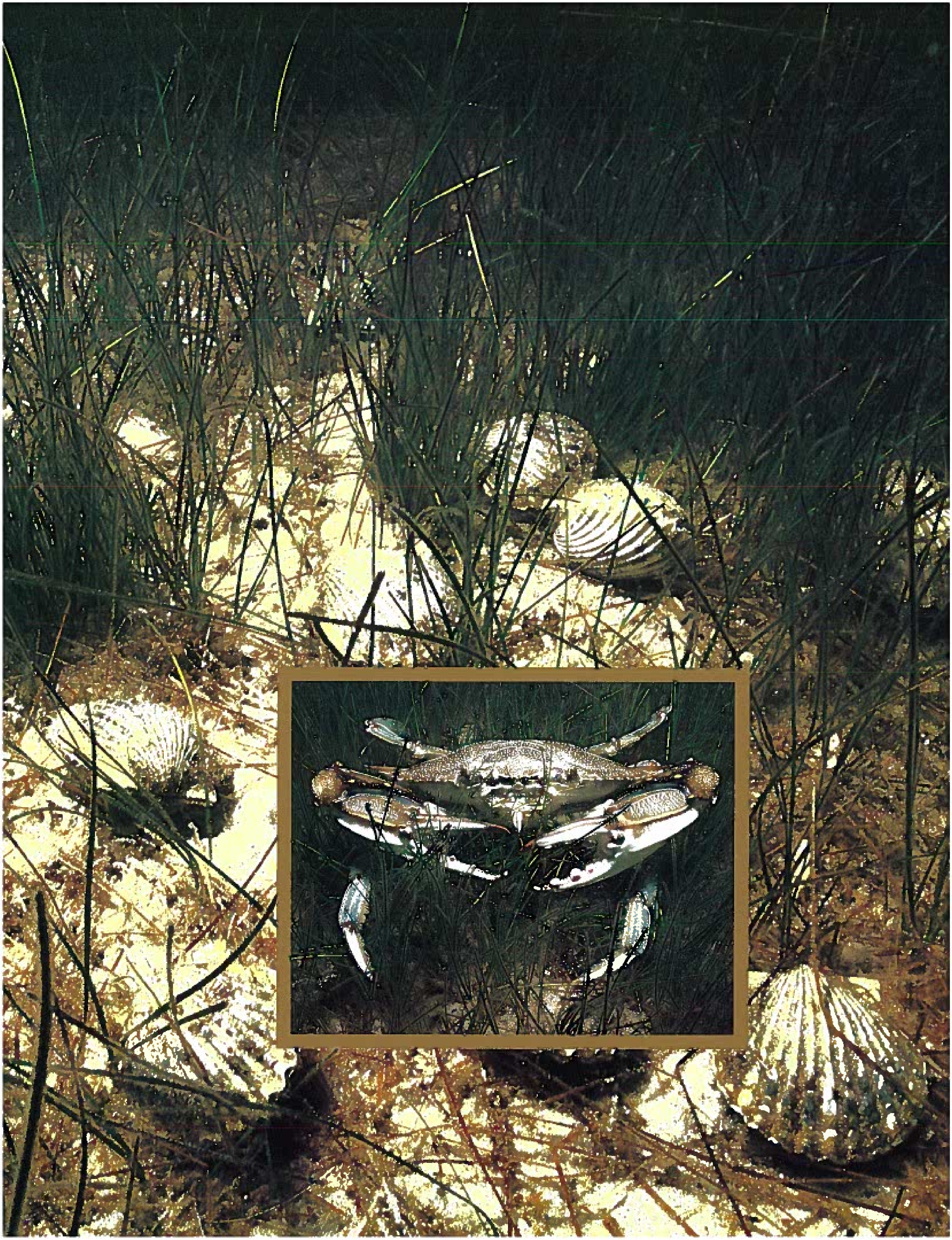

Seagrasses form one of the most productive plant communities on the planet. They provide valuable and virtually irreplaceable habitat for numerous recreational and commercial fishery organisms as well as their prey. Tremendous losses of this habitat have occurred in the Gulf of Mexico (and elsewhere), however, as a result of development within the coastal zone. To counter wetland losses, the Nation has adopted the National Wetland Policy Forum's (1988) recommendation of "no net loss" of wetland habitat. Seagrasses have sometimes been differentiated from wetlands because they occur primarily underwater. The well-documented ecological function and potential linkages among seagrass systems and other, more easily observed coastal plant communities, however, indicate that such a differentiation is semantic only. Seagrass habitat cannot be separated from the no net loss philosophy under any rational management strategy.

Losses to seagrass habitats may be slowed or even reversed through properly planned and executed planting projects. This handbook was developed to guide agency personnel, private consultants and others involved in wetland permitting, mitigation and restoration through the successful completion of these projects.

There is no easy way to plant seagrass beds and meet the goal of maintaining or increasing seagrass acreage. It is an inherently complicated process that does not lend itself to oversimplification. Such a tactic would be especially misleading to readers and seriously misrepresent the skill development and capital outlay required to develop a fully functional seagrass meadow. This, after all, is the implicit, but often unstated, goal of all seagrass plantings.

Reasons for seagrass planting

Value of seagrass beds

Seagrass beds are among the most productive of marine plant communities. At least 90 percent of the southeast United States seagrass acreage (*ca.* 1.1 million hectares) exists in the Gulf of Mexico[1] (Orth and van Montfrans, 1990) although the full extent and function of the reported 400,000 hectares of seasonal *Halophila* beds off the west coast of Florida have not been explored (Josselyn *et al.*, 1983, 1986; Kenworthy *et al.*, 1989). Seagrass beds are important not only in terms of the plant biomass produced (much of which provides food for bacteria and microscopic animals at the base of a complex food web), but also as a physically stable refuge and nursery ground for numerous commercially and recreationally valuable shrimp, fish and crabs and their prey (see reviews by Zieman, 1982; Phillips, 1984; Thayer *et al.*, 1984; Kenworthy *et al.*, 1988; Zieman and Zieman, 1989). The vast majority of landed commercial and recreational fish spend at least some portion of their life histories using seagrass beds. Chambers (1992) estimated that in 1983, 98 percent of the commercial landings in the Gulf of Mexico were estuarine-dependent.

Seagrass beds also provide important habitat for other wildlife. Migratory waterfowl such as redhead ducks feed on seagrass rhizomes directly. Green turtles and manatees eat seagrass leaves as a regular component of their diets. Wading birds frequent seagrass beds during low tides to feed on small fishes (e.g., toadfish, blennies, pinfish) that use the canopy and fibrous root and rhizome mat for shelter (Sogard *et al.*, 1989). Diving birds such as mergansers, loons and cormorants regularly feed over seagrass beds as well.

Seagrasses are unique among marine plants in their ability to bind shallow underwater sediments with their roots and rhizomes while simultaneously baffling waves and currents with their leafy canopy (Fonseca *et al.*, 1983; Fonseca and Fisher, 1986; Fonseca, 1989b; Fonseca and Cahalan, 1992). By baffling water motion, the canopy inhibits resuspension of fine particles and traps those already in the water column, providing a natural and highly effective water column cleansing capability (Ward *et al.*, 1984). This cleansing effect extends to water column nutrients as well. Seagrasses and their associated epiphytes and macroalgae readily take up dissolved nutrients for incorporation into plant biomass, thereby partially ameliorating poor water quality. The baffling effect of the canopy on sediment stabilization is enhanced by the presence of a robust root and rhizome mat. For example, the root and rhizome mat of turtlegrass (*Thalassia testudinum*), a common Gulf species, often does not even begin until 20 cm into the sediment (Zieman, 1982). Roots of this species may penetrate from 1 meter to several meters into the bottom (Zieman, 1975) while the rhizomes form a tightly woven mat approaching a half meter thick in mature beds (Zieman, 1982).

Seagrass losses in the Gulf of Mexico

Seagrass beds are dynamic systems, with some beds persisting essentially unchanged for decades and others changing with the season (den Hartog, 1971; Zieman and Wood, 1975; Phillips, 1980; Fonseca *et al.*, 1983; Duarte and Sand-Jensen, 1990). Some changes in seagrass communities can be attributed to the life histories of individual seagrass species. Natural perturbations, however, greatly influence the mosaic of species and extent of seagrass distribution. Physical disruption from storms and shifting channels redefines seagrass bed configuration and composition. Seasonal disturbances such as low tides that expose and desiccate beds (Phillips, 1980; Thayer *et al.*, 1984), as well as disastrous seasonal events such as hurricanes (Eleuterius and Miller, 1976; Livingston, 1987) can dramatically change seagrass community composition and bed size. Biological disturbance from burrowing activities of animals such as shrimp, crabs and rays can also be extensive. Overgrazing by herbivores such as urchins, manatees and turtles has also affected distribution and condition of seagrass beds (Camp *et al.*, 1973). Some dieoffs of seagrass, such as the "wasting disease" of eelgrass (*Zostera marina*) in the North Atlantic during the 1930s (Short *et al.*, 1988) and the current demise of turtlegrass in Florida Bay (Robblee *et al.*, 1991) have not yet been, and may never be, fully explained.

When human impacts are added to the natural stresses imposed on seagrass beds, additional losses of seagrass can occur (Orth and Moore, 1983; Cambridge and McComb, 1984). In the Gulf of Mexico, large scale losses have been documented (Livingston, 1987; Duke and Kruczynski, 1992). More than 50 percent of the historical seagrass cover in Tampa Bay has been lost (Haddad, 1989). Similarly, 35 percent of the seagrass acreage in Sarasota Bay has been lost, as well as 29 percent of that in Charlotte Harbor, Florida, (Haddad, 1989) and 76 percent of that in Mississippi Sound (Eleuterius, 1987). Pulich and White (1990) reported a loss of 90 percent in Galveston Bay, Texas. These reports are often from areas close to research groups capable of detecting and documenting losses. Unreported losses of equal or greater extent may exist in less studied areas.

Loss of seagrass cover leads to several undesirable, and difficult-to-reverse, conditions. First, the sediment-binding and water motion-baffling effects of the plants themselves are lost (Fonseca *et al.*, 1983; Fonseca and Fisher, 1986) allowing sediments to be more readily resuspended and moved. The physical ramification includes increased water

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[1] Defined for this document to run from the U.S.-Mexican border to the Florida Keys, including Florida Bay, although these findings may be applicable throughout the Caribbean basin and, in a generic sense, across much of the United States.

column turbidity and, potentially, shoreline erosion. Seagrass planted in areas with these conditions may grow poorly due to light limitation from the elevated turbidity. Loss of seagrass, of course, eliminates all important associated habitat functions (Kikuchi, 1980; Peterson, 1982).

Much of the documented seagrass loss is due to human-induced reductions in water transparency (Kenworthy and Haunert, 1991), and these losses are often not included with other wetland or even seagrass loss statistics. Seagrasses in the Gulf (and elsewhere) typically require that at least 15 to 25 percent of the light at the water surface penetrates to their leaves. However, permissible standards for water transparency are usually set at 1 percent of surface light (Kenworthy and Haunert, 1991), making the task of demonstrating the need for mitigative action difficult. Excess suspended solids and nutrients that enter the water column as the result of poor watershed management combine to reduce transmitted light below this critical level. Suspended solids (and associated water color changes) reduce water transparency directly, and extra nutrients accelerate growth of light-absorbing algae in the water column and on seagrass blades. When losses have occurred due to decreased light availability, often only changes in watershed management (such as controlling stormwater and sewerage discharges) can reverse the trend of decline. Such a reversal in decline is rare but has occurred (Johansson and Lewis, 1992). Transplanting into areas experiencing seagrass loss due to decreased water transparency without independent improvements in water quality will only result in the death of the transplants.

Reduction in water transparency is not the only anthropogenic cause of seagrass loss. Thermal effluents from electric power plants have caused extensive losses such as those documented at the Turkey Point station in Biscayne Bay, Florida, (Zieman and Wood, 1975) as well as those associated with the Crystal River and Stock Island (Key West) stations (pers. obs.). Dredge and fill impacts to seagrass beds are too numerous to document throughout the Gulf. In the past, losses due to dredge and fill activities were commonly associated with private sector development. More recently, however, many losses have resulted from public interest projects, such as the replacement of the Florida Keys Bridges (Mangrove Systems, Inc., 1985; Thayer et *al.*, 1985). In addition, the rapidly increasing number of small boats in Gulf waters has resulted in widespread damage from propeller scarring. The scope of this damage often appears innocuous when viewed from the vantage point of a small boat, but an aerial view often exposes a staggering breadth of destruction (Durako *et al.*, in press; R.R. Lewis, pers. com.; author, pers. obs.). In the case of turtlegrass beds, this damage is extremely long-lasting (Zieman, 1976). Not only is there lost productivity from chronic propeller scarring, but these areas become points of instability that are highly susceptible to sediment resuspension (decreased water transparency) and can lead to additional erosion from waves and tidal currents. Because of the chronic nature of propeller scarring, such damage is likely very difficult to repair by planting.

Planting seagrass to stop and reverse habitat losses

The National Wetlands Policy Forum (1988) recommended the following goals to protect the nation's wetlands: First, to achieve no net loss of wetlands through compensatory mitigation, or compensation through replacement, for all permitted habitat conversions; and second, to increase the quantity and quality of wetland resources through restoration of historically degraded habitats. Attaining these goals would result in a stable and eventually increasing national wetlands base. The remainder of this handbook will describe techniques for planting seagrasses to achieve these goals in nearshore habitats.

Although planting techniques exist, their record of success in establishing seagrass habitat is poor. Much emphasis was placed on technique development in the late 1970s and early 1980s (see reviews by Phillips, 1982; Lewis, 1987; Fonseca *et al.*, 1988), but relatively little attention was given to developing a management framework within which these techniques could be effectively implemented. Planting projects have often failed as a result of poor selection of planting sites or plant material and incorrect use of planting methods; these problems have been difficult to rectify due to insufficient monitoring of plant performance. As such, there has never been a report of a seagrass mitigation project in the Gulf of Mexico that has created enough acreage to achieve the goal of 1:1 habitat replacement (i.e., offset a net loss of seagrass habitat, *sensu* Fonseca *et al.*, 1987c; Fonseca, 1989a).

Mitigation is broadly defined to include avoidance and minimization of adverse environmental impacts (the latter term unfortunately implying an acceptable net loss of acreage). Because of the inherent difficulties in establishing seagrasses, plantings conducted in exchange for permitted losses (compensatory mitigation projects) could result in a net loss of habitat. Therefore, *a priori* decisions allowing compensation for loss of existing seagrass habitat by attempting to replace it should only be considered where impacts have been avoided to the fullest extent practicable.

Seagrass habitats must be restored to historical levels to achieve the long-term goals of the National Wetlands Policy Forum. When planting is done for compensatory purposes on sites that historically supported seagrass (where the cause of initial loss has ceased), one makes an implicit choice between offsetting present-day losses and returning toward historical baseline acreages. This is because use of historically degraded seagrass habitat as a compensatory mitigation option uses up bottom acreage that would otherwise be available for restoration (i.e., non-permit associated planting). The use of seagrass restoration as a mitigation option reduces the potential to effect a net increase in seagrass acreage over present-day levels and move toward higher, historical levels. Thus, decisions involving the selection of planting sites for compensatory mitigation ultimately will require resolving the conflict between short-term and long-term benefits.

Planning

There are several factors to consider when preparing for a seagrass planting project. The bold headings in the following subsections can serve as an abbreviated checklist of information requirements and subsequent actions that should be anticipated. The common thread among all these considerations is the need for early coordination with state and federal resource agencies. Since many states have a management system set up for agency review of such plans, early coordination can resolve many regulatory problems before they become costly.

Identify goals

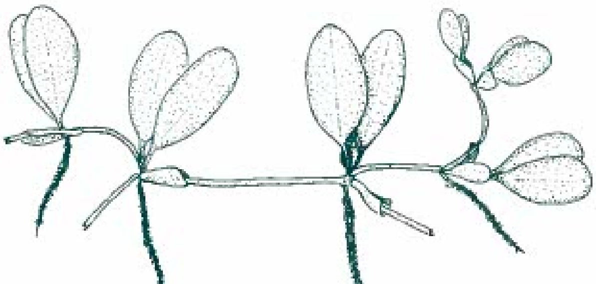
Begin by writing out generic and specific goals for the project. Although methods exist to plant seagrass, frequently the goals of a project are not defined. Is the project for restoration or compensatory mitigation? A restoration project undertaken for the sake of restoration only, not for mitigation, may not require performance criteria as stringent as those of a mitigation project, but must comply with stated goals and a scope of work. Although the differences in project goals have little to do with the execution of the planting technique, it is important to recognize that planting in exchange for permitted losses may elicit different responses from resource agencies than planting for the sake of restoration only. Fonseca (1989a) should be reviewed for a summary of agency concerns.

Project goals should identify the species of plants to be used. Attaining the same seagrass species as those lost is the most ecologically defensible goal. The six known species of seagrass found in the Gulf (Fig. 1, Table 1) occur together and have different potential for planting success based on their growth strategies. For seagrass planting projects to be successful, it is critical that consideration be given to the physiological requirements of the plants and their life histories. For example, species with a slow coverage rate (i.e., turtlegrass) are very difficult to restore in the time frame often allotted many projects. It can take years for a planting to re-create the dense root system, organic-rich substrate, and nutrient cycling capabilities of turtlegrass beds. Paddle grass (*Halophila decipiens*) has a very different strategy. This species often colonizes disturbed areas rapidly and requires relatively little light to grow. An individual leaf pair of paddle grass may live for only six weeks and produce many seeds, a strategy typical of species (including the other *Halophila* spp.) living at the extreme of its ecological limits. Its shallow root system however, makes it vulnerable to disturbance. Widgeongrass (*Ruppia maritima*) has a wide tolerance of salinities and grows in fresh water, brackish water, or among other seagrasses in full strength seawater. Like paddle grass, this species has a very high seed production and covers the bottom quickly. Finally, shoalgrass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*) have moderate coverage rates.

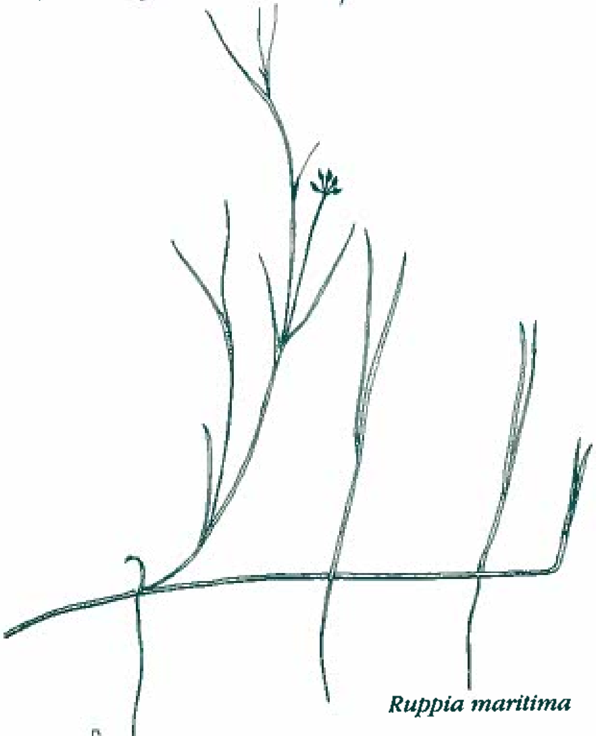
Because population growth rate varies with geographic location, the timetable for meeting project goals will vary as well. For example, it will typically require two years to restore a shoalgrass bed in the Florida panhandle whereas it may take only six months to restore the same species in the Florida Keys (Fonseca *et al.*, 1987c).

Site survey

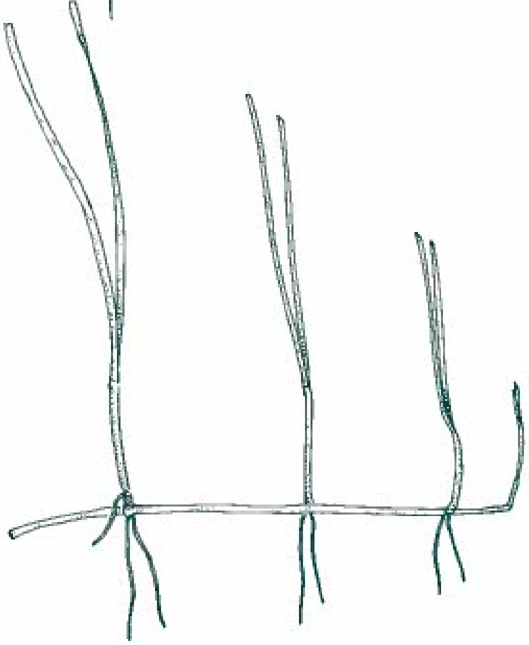
Surveys of the amount of plant material disturbed, its distribution, and the physical conditions at the



Halophila decipiens



Ruppia maritima



Halodule wrightii

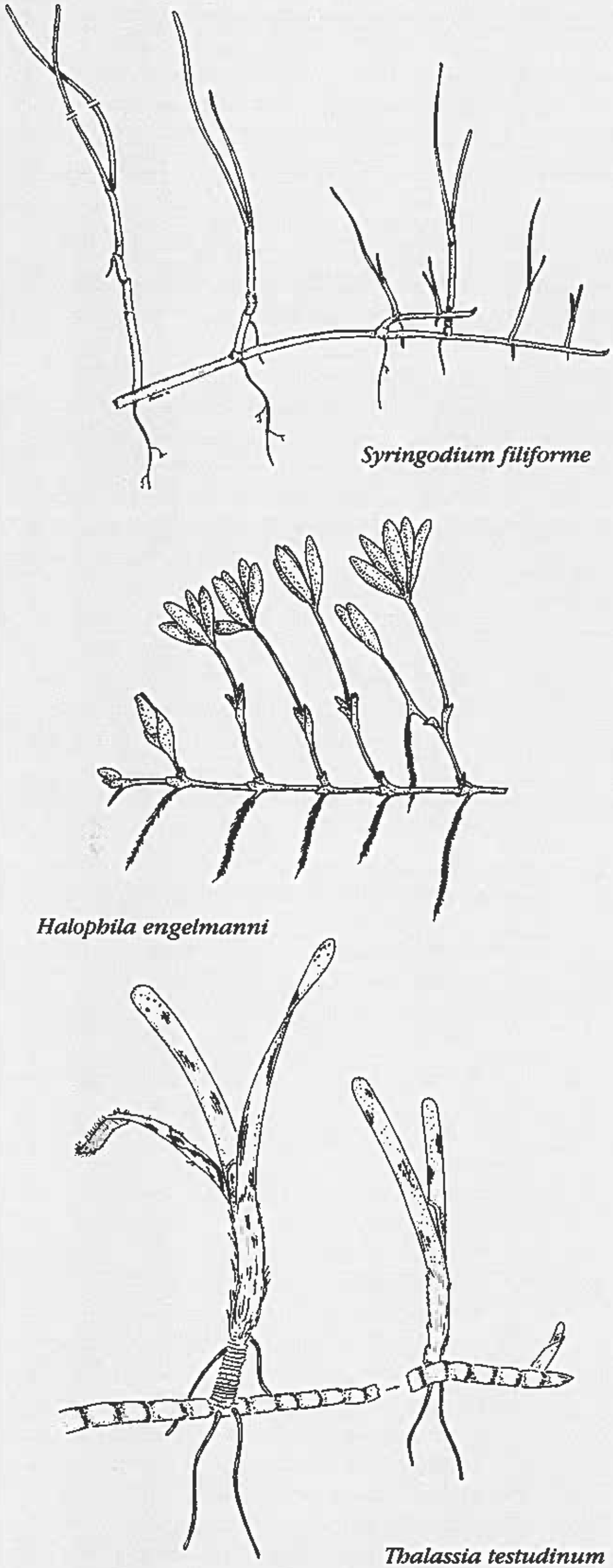


Figure 1. Seagrass species found in the Gulf of Mexico. All drawings by the author. Sources: field collections, and redrawings from R. Zieman (Zieman and Zieman 1989) and R. Phillips and E. Meñez (1988).

Table 1. List of seagrass species by family, genus and species, and common names (if available) that are found in the United States and adjacent waters. Species marked with (*) are known to be common to the Gulf of Mexico.

Family and species	**Common name**
Hydrocharitaceae	
* *Halophila decipiens* Ostenfeld	paddle grass
* *Halophila engelmanni* Ascherson	star grass
Halophila johnsonii Eiseman	Johnson's seagrass
* *Thalassia testudinum* Konig	turtlegrass
Potamogetonaceae	
* *Halodule wrightii* Ascherson	shoalgrass
Phyllospadix scouleri Hook	surf grass
Phyllospadix torreyi S. Watson	surf grass
* *Ruppia maritima* L.	widgeongrass
* *Syringodium filiforme* Kutz	manatee grass
Zostera japonica Aschers. et Graebner	
Zostera marina L.	eelgrass

impact and planting sites should be conducted prior to initiating a planting project.

Lockwood (1991) provided guidelines for surveying sites prior to impact and for interpreting these data to plan subsequent plantings. Essentially, any quantitative survey method will work, such as line transects or grid sampling. Sampling for the presence/absence of seagrass should encompass the entire impact site on the closest spacing practicable. The depth distribution and coverage of each species present should be recorded. If seagrass occurs in a patchy distribution, then the area occupied by the plants (portion of the seafloor where rhizomes overlap) should be recorded as the percent coverage. Notes on the shape and size of patches may also be useful in directing future planting efforts, allowing a planting pattern similar to that of the original beds to be developed. Data on species composition should be used to guide the selection of species for later planting. Further, these data can be used to determine the amount of seagrass that can be salvaged for planting other sites or potentially stored for replanting onto the original site if the disturbance is short-lived.

Aerial photographs can provide useful information for evaluating existing seagrass beds. A time series of aerial photographs, if available, can be particularly useful in determining the dynamic nature of a site. They can also be useful in documenting the prior existence of beds, thereby discouraging their surreptitious destruction prior to permit applications (pers. obs.). For the best delineation of coverage, photographs should be used only if taken during the peak growing season for the seagrass in question (latter part of summer for the Gulf).

It is difficult to determine the lower depth limit of seagrass accurately on a site from aerial photographs. Lower depth limits of seagrass distribution should be verified by concurrent on-site inspection, especially if bottom features that are clearly deeper than the apparent lower limit of the seagrass in the picture cannot be discerned in the photographs.

Aerial photographs can be

useful in judging the suitability of a site for planting seagrass beds. If historical aerial photographs indicate no history of seagrass cover, then the potential planting site should be rejected. Episodic seagrass cover on a potential planting site, either among years or seasons (as might be the case with seed recruitment) would suggest that planting there would only provide temporary cover and not provide sustained habitat replacement. As these caveats imply, it is very difficult to locate a planting site that will provide self-sustained habitat at a one-to-one replacement level with existing acreage.

A precise survey of the physical conditions at the planting site will assist in determining the amount of plant material required later. In the case of mitigation projects, a similarly precise survey of conditions prior to any proposed impact is required to obtain an accurate estimate of the seagrass habitat to be lost. This will allow accurate planting ratios (mitigated acreage vs. impacted acreage) to be computed. For example, if 0.5 acres of continuous cover seagrass bed (e.g., a site with low wave energy and/or low tidal current velocity) were lost to a project and a planting site with high wave energy and/or current velocity were chosen that would typically support patchy beds with, for example, only 50 percent coverage, then one would have to:

1. anticipate planting over an acre of bottom to achieve 0.5 acres of cover (either as continuous planting or grouped to imitate patch formation), and
2. budget for substantial replanting (as much as 50 percent of the original planting) since planting failures increase with higher currents (Fonseca *et al.*, 1985).

There are additional factors that substantiate the need for a replanting budget. For example, Meyer *et al.* (1990) found that even in areas of Tampa Bay where currents were low (did not exceed 13 cm/sec), more than 50 percent loss of planting units was experienced due to sediment disturbance, apparently by rays. Merkel (1988a) also found extensive disturbance of seagrass transplants in San Diego Bay. The lack of good pre-project information, such as the potential for bioturbation, will usually cost one more in remedial planting than will be saved from planting a minimum of material at the onset.

Environmental data or pilot test planting results should be available to provide an indication of planting success prior to the commitment of the entire project's resources. However, some plantings may be sufficiently small (*ca.* 500 planting units) that the cost of such pre-project data collection is equivalent to the cost of planting the entire site itself.

Site selection

Selecting a potential planting site can be the single most important step in the entire process. It is also the step that is the most difficult to verify objectively because the circumstances contributing to the presence or absence of seagrass at a given site vary tremendously. Proposed planting sites must pass a simple, but exacting, test: "If seagrass does not currently exist at the (chosen) site, what makes you believe it can be successfully established?" (Fredette *et al.*, 1985). **If there is no tangible evidence to indicate that a site once supported seagrass (e.g., historical aerial photographs, reliable site surveys), or if the suspected cause of seagrass decline has not abated, then the site must be rejected.** The absence of seagrass on what may appear to be an otherwise suitable site often indicates some inherent difficulty in colonization. Similarly, planting among patches of existing natural seagrass (naturally unvegetated seafloor should not be substituted for vegetated bottom) should also be rejected because this, too, will only provide temporary habitat and not create any long-term increase in seagrass acreage.

Salinity and temperature tolerances of seagrass species must be considered when selecting planting locations. Most seagrasses (except widgeongrass) cannot grow at salinities below 17 ppt, and the effect of periodicity and duration of extremes in salinity on seagrass survival are poorly documented (see review by Zieman and Zieman, 1989). Matching salinity regimes between the planting site and donor site is, therefore, strongly recommended. Temperature regimes should be similar as well. Temperature extremes may be problematic if a planting site has restricted circulation, allowing water temperatures to rise above levels found in the donor beds.

Planting areas for compensatory mitigation may be classified as either on-site or off-site. On-site plantings are conducted within the area of disturbance on impacted sites, whereas off-site plantings are conducted at locations some distance from the impacted sites. There are usually few, if any, off-site locations available that (a) can support seagrass growth, and (b) do not involve habitat substitution.

One form of off-site planting that meets the criteria discussed above is the creation of habitat by scraping down uplands to elevations suitable for planting. Although this entails the trade-off of upland habitat for seagrass, if that upland is zoned for development, then its conversion to another habitat type may be warranted. Other off-site options include dredged areas that have been filled or areas that have experienced an improvement in water quality (e.g., transparency, temperature, etc.). These latter two choices, however, may include previously vegetated areas with strong potential for natural revegetation or restoration, and thus may not be appropriate to offset seagrass loss in compensatory mitigation.

In the case of on-site planting associated with a particular project (i.e., planting back into the portion of the site that suffered a loss of seagrass), the activity that originally caused the loss of seagrass must have ceased. On-site planting often entails planting into permanently modified areas, such as dredged channels, which cannot accommodate any planting ratio above 1:1 (one unit area planted for one unit area lost), eliminating the option of higher ratios. Planting along channel banks is logical if the depth of planting does not exceed that at which the plants occurred prior to dredging (pre-project data on extent and depth distribution of seagrasses is invaluable for planning post-impact planting). In many portions of the Gulf, channel bottoms of useful navigational depths will not support seagrass. Insufficient light (a minimum of 25 percent of the light reaching the water surface must reach the plants for about six hours each day), insufficient sediment thickness (e.g., bedrock too near the surface for a given species), trapping of plant litter in the channel bottom (covering any colonizing plants and causing anoxia), or severe scour from propwash combine to render many channel bottoms a stressful, if not lethal, environment for seagrasses.

Conversely, reduced water depth from dredge material deposition may result in sites where transplants would be exposed at low tides, causing them to desiccate. Sufficient water depth must be maintained to cover the plants even at lowest tides. Even very short-term low tide exposure (two to three hours) may substantially alter seagrass abundance and distribution. For example, desiccation caused by an extreme low tide at midday in the summer can determine the upper limit of seagrass distribution for the following year (pers. obs). Areas with high turbidity and tidal amplitudes are extremely difficult to plant given the balance that must be struck between desiccation at low tide and light extinction at the lower depth limit.

If significant physical alteration has occurred to a site, on-site plantings often cannot provide sufficient acreage to prevent a net loss of habitat. One common physical alteration preventing transplant survival is the dredging of a seagrass bed. Another common, but less obvious physical alteration occurs when bulkheads are installed. Many bulkheads are designed as walls to reflect waves efficiently. This wave reflection effectively doubles the wave energy seaward of the wall, often eroding existing offshore beds and creating a situation where they cannot be reestablished. When physical alterations are subsequently ameliorated, on-site planting is appropriate and offers one of the few circumstances where substantial acreage can be generated, even though historical levels may not be attainable.

Stock selection, availability and performance

The choice of species is often dictated by project goals, such as the desire to replace in kind the seagrass species that was lost. However, the three species of seagrass that have commonly been used for planting in the Gulf states (shoalgrass, manatee grass and turtlegrass) have very different coverage rates (Fonseca *et al.*, 1987c). Coverage rates of the common species are shoalgrass > manatee grass > turtlegrass. Any of these species can be planted alone, but shoalgrass is considered a pioneering species and should be used to establish cover quickly. Shoalgrass may also be planted in alternating rows with manatee grass. Although turtlegrass may be planted alone, it exhibits very slow population growth and coverage rates under transplant conditions, which makes it susceptible to interim erosion. The prolonged lack of cover would also likely extend the period of interim loss of fishery resources. If turtlegrass is the target species, it should be added to areas planted with the faster-growing species (e.g., shoalgrass) once they have stabilized the bottom. There is little written information regarding planting procedures for other Gulf seagrasses.

Widgeongrass performs similarly to shoalgrass when transplanted and can be planted using the same techniques (Stout and Heck, 1991). The H*alophila* species (paddle grass and star grass) are extremely fragile, but can significantly reduce near-bottom currents and wave scour (Fonseca, 1989b). Because of their growth strategy, with only three or four leaf pairs on a rhizome in close proximity to the rhizome apical meristem, or growing tip, these species would likely be suitable for transplanting using the peat pot method described on subsequent pages. The author has successfully transplanted bare root sprigs of paddle grass in 15 m of water with moderate wave exposure by "stapling" the plants to the bottom until rooted with a 60-pound test wire fishing leader bent into a U-shape. While few cases of *Halophila* spp. transplanting have been documented, their pioneering growth strategy and small size make them likely candidates for effective use in planting projects.

Procurement of planting stocks

At this time, virtually all planting material must be obtained from existing, wild vegetative stocks. Laboratory culture of plant fragments for large-scale field plantings is an active research area (Durako and Moffler, 1981, 1984; Lewis, 1987, 1990) and may ultimately provide the necessary material and means of matching stock with environmental conditions for field plantings. Collecting vegetative material from existing beds is rigorously managed in many states, and collection without appropriate permits may result in civil or criminal prosecution. Because of the evolving nature of the field of restoration science, it is imperative that those planning seagrass planting carefully coordinate their actions with state and local governments. It is not uncommon to find permits required from not only the federal government, but numerous state and local agencies as well. It could take months to receive a permit because of the increasing volume of requests reaching permitting agencies. Such a delay must be anticipated in order to collect plants (if approved) and plant at the desired time of the year.

Wild stocks are usually used once planting is permitted. Shoalgrass and manatee grass can be harvested from wild stands with a reasonable assurance of recovery of the harvest site (Fonseca *et al.*, 1990b). Although not currently documented, it is highly probable that widgeongrass, paddle grass and star grass in low current areas would recolonize small harvest patches quickly (< 0.25 m^2 patches returning to normal density within one year) because of their high population growth rate and seed production. Harvest from areas with high exposure to waves, however, could initiate the development of an erosion scarp that would spread and damage the donor bed irreparably (*sensu* Patriquin, 1975). In areas of high current or wave exposure where beds occur as patches, harvest should be conducted only at the bed margins to prevent scarp formation. Turtlegrass can be transplanted with good survival (Fonseca *et al.*, 1987a,c; Fonseca, 1989a; Lewis, 1987, and references therein), but harvest damage to those donor beds may last for years (Zieman, 1976; Fonseca *et al.*, 1987c). Harvest of vegetative turtlegrass stock should be minimized or limited to salvage operations. Turtlegrass planting stock also can be acquired by harvesting the seeds that wash up on shore (Lewis and Phillips, 1980), which has no negative influence on existing beds. The impact of harvest of viable seeds or seedlings of any species collected from within existing beds or colonizing areas has an unknown effect on the maintenance of seagrass in those areas and should be discouraged.

Stock should be selected from a site with conditions as similar as possible to the planting site. There should be similar or equal water depths, salinity, temperature, tidal currents and wave exposure. Matching sediment types of the donor site with the planting site (percent silt and clay, and percent organic matter content of the sediment) is also suspected to facilitate transplant success. The concept of choosing plants of the same size as those lost, perhaps accounting for potential races of seagrass, was suggested 45 years ago (Addy, 1947). Little data have emerged for Gulf species to suggest changing this practice, although concerns have been voiced regarding the maintenance of genetic diversity in transplanted eelgrass (S. Williams, pers. com.). Until more is known about the genetic structure of seagrass ecosystems, in the form of experimentally derived evidence regarding the role of genetic diversity in planting success, matching of phenotypes among impact and donor sites remains the best guide for stock selection. Planting material may become available as salvage prior to the imposition of a project. Utilization of salvaged material requires good up-front organization so that a planting site is available before the plants are destroyed (e.g., turtlegrass, Lewis, 1987). Long-term storage of salvaged plant material to use for future plantings has not been scientifically evaluated, but has been accomplished for at least a week (pers. obs.). Longer term storage may be possible but will significantly increase handling costs.

It would be prudent to create transplanted beds for the sole purpose of providing donor material to subsequent operations. This would alleviate the problems of storage costs, relieve some of the time constraints and permitting problems that accompany most projects, and prevent damage to native seagrass beds. Once these (or any) beds are planted, however, they fall under the permit jurisdiction of resource agencies as would any seagrass bed. Therefore, planting of beds for future donor material needs to be organized early and in coordination with permitting agencies.

Planting

Appropriate methods

Development and implementation of appropriate methods requires experience and familiarity with species' growth habits and life histories. Numerous methods have been shown to establish seagrass successfully; however, familiarity with handling and planting methods, as well as the ability to work in or under the water, are requisite. The familiarity of an individual with these plant communities is inversely proportional to the difficulty encountered in executing a planting. Low-bid contractors must at least have seen the species involved and, if needed, have the ability to snorkel or SCUBA dive. Inexperience can lead to project failure.

Planting strategies can be divided into SCUBA and non-SCUBA assisted operations. In either case, once the required acreage for planting is decided, the planting area should be clearly marked off so its boundaries are visible from the surface (e.g., poles, buoys). Experienced boat operators and SCUBA divers may be required. The decision to utilize SCUBA does not necessarily mean that depths are over one's head. Where the water is deep enough to prevent a snorkeling diver from reaching the bottom without breath-holding, a person walking and either handing planting units (PUs) to the diver or pre-placing them for installation can greatly reduce physical exertion. Various combinations of planting and providing PUs to the planter will work effectively. Some experimentation will typically improve efficiency by best utilizing the skills of the personnel involved.

Plug method

Plugs of seagrass with the associated sediment can be harvested using a core tube. Core tubes (Fig. 2) are used to remove plugs from the donor bed and transport them in the tube to the planting site. The tube (usually 4- to 6-inch diameter PVC) is inserted into the

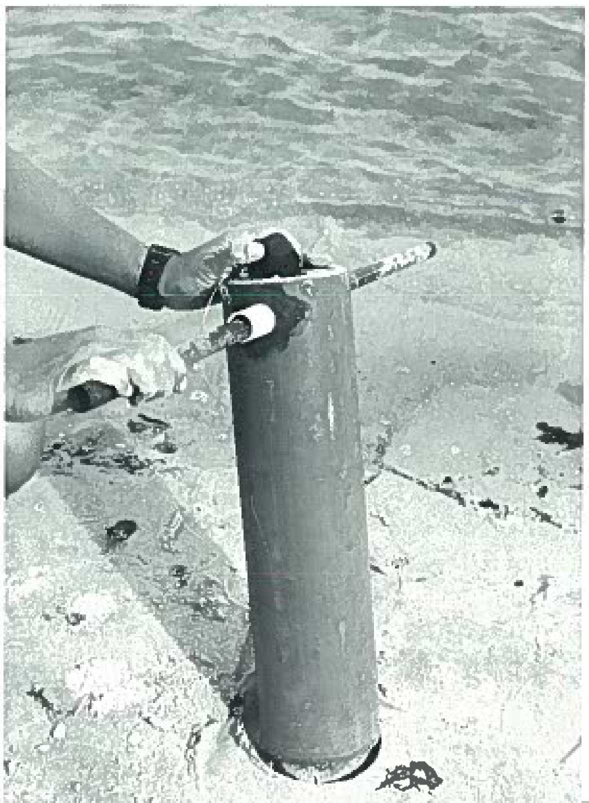


Figure 2. Demonstration of core tube on sand beach. Planting on beach for demonstration only. (Top) 4-inch diameter PVC core tube with 1-inch PVC tube installed and sealed. Removable metal handle inserted in tube for coring. Rubber stopper loose on top for insertion into sediment. Note beveled lower edge of 4-inch tube to aid in cutting rhizomes. (Right) Core tube after twisting into sediment to depth of ca. 20 cm. Rubber stopper is in place in plywood plug that was screwed in place and bedded in sealant. Placement of the stopper creates a vacuum that allows the plug of seagrass to be withdrawn from the substrate. Removal of the stopper allows the plug to slide out of the tube into the substrate for planting.

sediment while carefully guiding seagrass blades into the tube (to reduce blade shearing by the tube) and then capped (or stoppered as shown in Figure 2) creating a vacuum so that when the tube is pulled from the sediment, the small plug of seagrass with associated sediment is carried inside. Another cap is placed over the bottom to avoid losing the plug in transport. Another hole must be made at the planting site to accommodate the plug. This can be accomplished either by removing another core or by softening the bottom using a wedge. Fonseca et *al.* (1990b) used tree planting bars of the kind used in forestry practices for this purpose. To plant the plug, the bottom cap is removed from the core tube and the core tube is inserted into the new hole. The top cap is then removed, letting the plug slide out of the tube into the substrate. This method requires handling the caps and core tubes between planting and the next harvesting. Because of this handling time, the core tube planting method is the most expensive[2] (3.53 work-minutes per PU) tested by Fonseca *et al.* (1990b). This method has been used extensively, however, with good results for most species.

Staple method

The staple method has been used widely since its development in the late 1970s (Derrenbacker and Lewis, 1982; Fonseca *et al.*, 1982). The plants are dug up using shovels, the sediment is shaken from the roots and rhizomes as they are dug, and the whole plants are placed in flowing seawater tanks (or floating pens) for holding until made into PUs. Groups of plants are then attached to staples by inserting the root-rhizome portion of the group under the bridge of the staple and

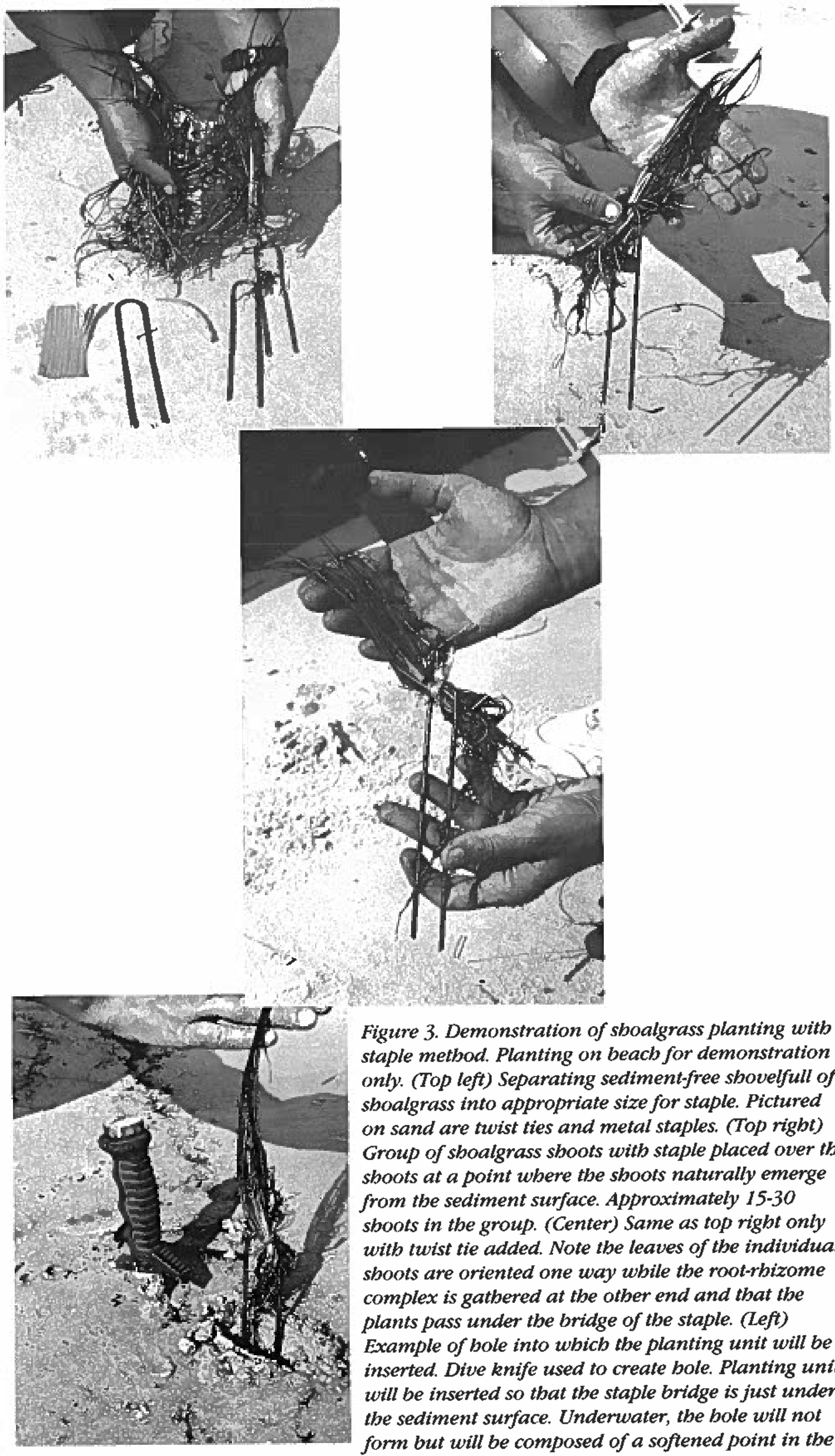


Figure 3. Demonstration of shoalgrass planting with staple method. Planting on beach for demonstration only. (Top left) Separating sediment-free shovelfull of shoalgrass into appropriate size for staple. Pictured on sand are twist ties and metal staples. (Top right) Group of shoalgrass shoots with staple placed over the shoots at a point where the shoots naturally emerge from the sediment surface. Approximately 15-30 shoots in the group. (Center) Same as top right only with twist tie added. Note the leaves of the individual shoots are oriented one way while the root-rhizome complex is gathered at the other end and that the plants pass under the bridge of the staple. (Left) Example of hole into which the planting unit will be inserted. Dive knife used to create hole. Planting unit will be inserted so that the staple bridge is just under the sediment surface. Underwater, the hole will not form but will be composed of a softened point in the bottom into which the planting unit will easily insert.

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[2] Costs for all methods included only work time to harvest, fabricate planting units and plant those units. No transportation time, lodging, capital expenditure for equipment, boats or overhead was included. Basic cost may then be computed by multiplying the number of PUs needed by time per PU and then by hourly wage.

securing the plants with a paper (not plastic) coated, metal twist-tie (Fig. 3). The twist-tie is secured around the plants at the meristem so that the leaves will extend from under the staple up into the water column when planted. A small strip of paper has been used to protect the rhizomes from the twist-tie by wrapping the group of plants with the paper and securing the twist-tie over the paper strip. The staples are then inserted into the sediment so that the roots and rhizomes are buried (Fonseca *et al.*, 1982, 1984). Loosening the sediment with a utensil such as a dive knife facilitates placing the roots into the sediment. One person can lay out the PUs beforehand at the desired spacing, while a second person follows and installs them.

This planting method takes less time than the core tubes, but the intermediary step of attaching plants to staples is time consuming. In areas with low wave energy and current velocity, groups of plants may be stapled to the bottom without attaching them to the staples beforehand. When attached to the staples, these plantings have successfully withstood tidal velocities of up to *ca.* 50 cm/sec (Fonseca *et al.*, 1985). The staple method required 1.91 to 2.07 work minutes per PU in a test by Fonseca *et al.* (1990b). The relatively low cost and widely tested applicability make this the most acceptable method available at this time.

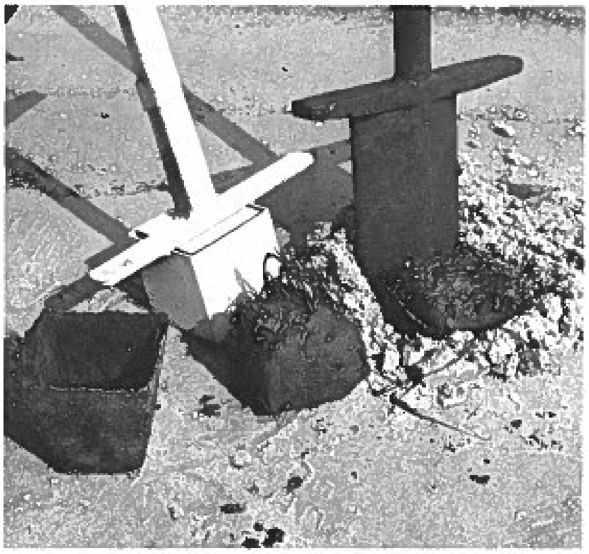
Some criticism has been leveled at the use of metal staples, because the bridge of the staples will oxidize before the legs that are deeper in the typically anaerobic sediment, leaving two potentially sharp pieces of metal in the bottom (Merkel, 1988b and unpublished references therein). The use of metal staples described here is emphasized for its sediment-free approach, reducing the burden of carrying associated sediment. Any other degradable anchor may be substituted if shown to provide similar stabilization of the plantings until they root.

Peat pot method

Fonseca *et al.* (1990b) recently developed a new method of transplant-

Figure 4. Demonstration of peat pot planting method with shoalgrass (on beach for demonstration only). (Left) Pictured are plugger (on left) and tree planting bar (on right). The plugger has a 3-inch square cutting box with a step on top for insertion into the bottom. A rod runs from the handles down to a plate inside the cutting box, which is used to expel the cut plug into the peat pot forcibly. Also pictured is a plug, peat pot, and plug in a peat pot.

(Right) Close-up of cutting box of plugger with expulsion plate retracted to the top of the cutting box. The extruded shoalgrass plug is being held in this case but is typically released directly into the accompanying peat pot (right of picture). Note the plug is above the top of the pot. There is a 1- to 3-cm air pocket between the bottom of the plug and the pot bottom. This will be displaced when submerged but may capsize the planting unit. Placement of a metal mesh over the tray of peat pots is suggested before submerging the tray for storage.



(Left) Close up of empty peat pot, the plug as it would emerge from the cutting box and on the right, the tree planting bar having loosened a hole into which the entire unit will be placed. The pot walls will then be torn down as it is inserted into the sediment to let the rhizomes spread. As with staples, the tree planting bar will not form a hole but rather a loosened point in the bottom into which the peat pot can be inserted. The peat pot walls must be torn off or pushed down into the sediment because the rhizomes of the seagrass will not penetrate the pot wall, thus inhibiting spread.

ing similar to that of Robilliard and Porter (1976). Peat pot plantings have been found to have the lowest cost per planting unit (1.21 to 1.49 work minutes per PU), despite the fact that substantial amounts of sediment are moved with the plants (Fonseca *et al.*, 1990b). Similar to the problem identified with the coring method, shearing of blades by use of a sod plugger may impair growth of larger plants. Shoalgrass and potentially widgeongrass and paddle grass (or any *Halophila* species) may be most suitable for this method, given their relatively high density and generally shorter blade lengths than manatee grass. The peat pots used by Fonseca *et al.* (1990b) were 3 inches on a side and are readily available. A sod plugger is used to cut plugs from existing beds. The 3 x 3-inch sod plugger (Fig. 4) used by Fonseca et *al.* (1990b) can usually be purchased locally. The plug should be extruded immediately after collection into a peat pot and placed in a holding tray. Typically, one person cuts plugs and ejects them from the sod plugger into peat pots held by a second person, who then arranges the pots in a floating tray. As the trays fill up, they may be sunk to the bottom until moved to the planting site. Either all air trapped in the peat pot under the plug must be squeezed out prior to submergence or a heavy mesh lid (e.g., aluminum grating) should be placed over the tray, or else the pots will capsize in the tray. The tray can be stabilized on the bottom by placing a layer of wet burlap over the plants with an aluminum grid laid on top for ballast. The trays should be of a size to facilitate handling (*ca.* 30 pots per tray).

Planting can be accomplished in a number of ways. As with most of these methods, the PUs may be laid out by one person while others follow to plant them. One person loosens the sediment with a tree planting bar while the other person installs the peat pot in the bottom. Once in the bottom, the sides of the peat pot must be ripped down to allow rhizome spread. The rhizomes will not penetrate the peat pot wall. Despite their low cost, use of peat pots must be evaluated over a wide range of conditions and plant sizes before this technique is universally recommended.

Other methods

Other methods are reviewed by Phillips (1982) and Fonseca *et al.* (1988). These include the use of whole sods, plastic pots, iron rods, concrete rings, wire mesh, plastic bags, nails and seeds. The reader should note that introduction of plastics into the marine environment is now prohibited. In some areas, widgeongrass has reportedly been intertwined in biodegradable mats, which are then pinned to the bottom. Mats can be prepared for planting by placing them in natural beds and allowing plants to grow over them. Sowing seeds of seagrass has been studied for a temperate species (Orth, pers. com.). Others have attempted planting of freshwater and brackish water species using biodegradable mesh bags containing PUs dropped overboard with good success (Korschgen and Green, 1988), but these methods have only been tested in small-scale experiments. A patented turtlegrass-seedling growout method has been registered by Lewis (1987). These methods appear to work, but are ultimately dependent on wild stock harvest of seeds. Laboratory research is being conducted on large-scale production of planting stock using tissue culture techniques (e.g., Lewis, 1990), but this method has not yet been perfected (M. Durako, pers. com.).

Fertilizer effects

A potential advantage to the peat pot method over staples is that slow-release fertilizer may be added easily to the pots and installed with the plantings at little additional handling cost. An innovative technique is needed to add fertilizer to the sediment with other planting methods. Previous work by Orth (1977), Fonseca e*t al.* (1987b), and Kenworthy and Fonseca (1992) has met with mixed results, due at least in part to inconsistent performance of the fertilizer. Fonseca *et al.* (1990b) did find slow-release pellets to be empty after the prescribed 70-day release period, with all their fertilizer apparently solubilized. Although phosphorus additions to sediments with 1 to 2 percent carbonate content initially appeared promising, physical disturbance of the plantings may have obscured any positive influence. Only nitrogen additions had any significant effect. These results differ from those of Short *et al.* (1985) and Powell *et al.* (1989)—possibly due to the disturbance of the plantings—who found phosphorus-linked stimulation of seagrass productivity in carbonate sediments in well-controlled experiments. Fonseca e*t al.* (1990b) and Kenworthy and Fonseca (1992) recommend that peat pot plantings of shoalgrass in sediments containing >1.0 percent carbonate may benefit substantially from initial additions of slow-release phosphorus fertilizer.

While not to be discounted, the influence of fertilizer on plantings has not been predictable. No change in planting strategy should be enacted based on an anticipated benefit from fertilizer. There is no indication that fertilizer has been detrimental at the tested dosages. The added cost is minimal with some methods (e.g., peat pots) and the results have been either positive or neutral.

Spacing of planting units

Much attention has been given to row spacing of plantings (Fonseca *et al.*, 1982, 1984, 1985, 1987b, 1987c; Merkel, 1988b). The reader is directed to those references for a detailed study of the derivation of appropriate spacing. In practice, PU spacing ranges from 0.5 to 2.0 m on center. More rapid coalescence (the point where individual PUs grow together, obscuring the PU origin of individual shoots) is logically achieved with higher planting density. The benefit of increased rate of coalescence is offset by substantially higher costs due to the number of PUs involved. For example, a 100 m X 100 m (1 hectare) planting area planted on 2.0, 1.0, or 0.5 m centers would require 2500, 10000, or 40000 PUs, respectively.

Coalescence of a site planted on 0.5 m centers may take more than a year in areas such as Tampa Bay, Laguna Madre and the Florida panhandle, while plantings on 1.0 m centers in the Florida

Keys may coalesce within nine months. The rate of coalescence will decrease roughly in proportion to the spacing of the PUs. Plantings of shoalgrass on 2.0-m centers may be expected to coalesce in three to four years throughout most of the Gulf. One must keep in mind that during this interim period the planting area is not fully stabilized and disturbance (from storms, animal burrowing, etc.) may hinder final coalescence of the planting.

In areas with currents over 30 cm/sec or with long fetches (over 1 km), one may anticipate that the seagrass beds do not naturally cover the bottom completely (den Hartog, 1971; Patriquin, 1975; Fonseca *et al.*, 1983). In these instances, planting at high densities such as 0.5 m centers, in groups of plantings 5 to 10 m on a side, will probably improve the chance of survival.

Common methodological considerations

Some fundamental constraints are common to all planting methods. It is important to ensure the presence of growing tips (rhizome apical meristems) in individual PUs (Fig. 1). Visually inspecting arbitrarily selected planting units for the presence of at least one apical shoot per PU is recommended. The number of short shoots on a long shoot should be maximized whenever possible. Fonseca *et al.* (1987a) used an average of 2.6 short shoots per long shoot with turtlegrass. However, Tomasko *et al.* (1991) found higher rates of new short shoot production when long shoots were planted with more short shoots on them. It is also recommended that whenever possible, plants should be collected and planted on the same day. Too many times containers leak, become anoxic or become overheated when left unattended. Any number of incidents may further shock the plants and inhibit their photosynthetic capacity for prolonged periods after planting. Seagrasses are inherently fragile, having evolved in a fluid medium that provides support for their structure. When out of the water, they are very susceptible to physical damage. **To maximize planting success, it is critical that seagrasses are kept wet and handled gently.** The plants have very little resistance to desiccation. On a breezy, sunny day, plants left out of the water in the open can be killed in minutes. Plants must be kept in ambient temperature and salinity water at all times. They may be covered with seawater-soaked burlap for short periods if transportation is necessary. Stacking of the plants on one another should be minimized. Although they appear and even feel robust, they are easily bruised and broken. All other efforts will be rendered moot if the plants are not handled with extreme care.

Bioturbation is another factor mentioned frequently (Valentine and Heck, 1991). Disruption of early stage plantings by bioturbation has been widely reported. Losses appear to vary widely, ranging from 0 to 100 percent. Fifty percent losses are not uncommon where bioturbation is present. Merkel (1988a) and Fonseca *et al.* (1991) have demonstrated reduction in PU loss through the use of various bioturbation exclusion devices. Incorporation of these devices, which are little more than stakes or large (3 x 3 m) wire mesh cages, into the planting plan may reduce overall project cost and accelerate development of a functional seagrass bed. The primary agents of bioturbation in the Gulf are rays, crabs (blue and stone), sea urchins, ghost shrimp, and sand dollars. Depending on which animals appear to be prevalent, different exclusion methods may be warranted. Little research has been done on this topic and experimentation is encouraged.

Evaluating success: monitoring

There must be a clear definition of success to promote effective restoration and mitigation. Success is, however, a relative term. Planting seagrasses is an attempt to establish a viable plant community that performs habitat functions equal to ones that were lost. The evaluation of all seagrass ecosystem functions (sediment stabilization, biomass production, nutrient cycling, secondary production of fishery resources and their prey) is far beyond the resources of any project, and many research facilities. Research is underway to identify diagnostic parameters that can be monitored inexpensively to infer (with reasonable certainty) that specific functional attributes have been restored. Many habitat functions appear to relate simply to coverage (not shoot density) and persistence of that coverage; these parameters are monitored inexpensively (Fonseca *et al.*, 1990a; Meyer *et al.*, 1990). Seagrass planting success can, therefore, be defined as the unassisted persistence of the required acreage of seagrass coverage for a prescribed period of time (suggested minimum of three years). The required acreage is a result of replanting ratios, which is, in turn, a function of agency policy and the nature of the planting site itself.

Fonseca (1989a) described what to monitor, how to perform the monitoring, and how to interpret the results. The following are modified excerpts from that publication.

Monitoring specifications

Several factors must be considered in the development of a monitoring program to characterize seagrass planting success (Fonseca *et al.*, 1987c; Fonseca, 1989a). The extent of monitoring also can vary with the goals of the project. For example, restoration projects might not require the detailed monitoring of compensatory mitigation projects. Sufficient monitoring of all projects should be conducted to ensure that any contracted work was performed to specifications. In any situation, monitoring of planting performance using standard methods provides the basis for mid-course corrections (Fonseca, 1989a) and improved planting of subsequent projects. This scenario clearly fits where non-point source water quality problems have been ameliorated and seagrass bed development can be accelerated by planting, perhaps by years (e.g., Hillsborough Bay, Florida).

Survival

The number of PUs that survive should be recorded. This may be expressed as a percentage of the original number, but the actual whole number is critical as well. If a planting site is sufficiently small, all planting units should be surveyed for presence or absence (survival survey). The existence of a single short shoot on a planting unit indicates survival of the PU. If a site is large, then randomly (not arbitrarily) selected rows or subsections (area in square meters) should be sampled. Since each row or subsection is actually the level of replication, at least 10 replicate rows or subsections should be performed at the scale over which one wishes to generalize the findings (e.g., over the whole planting site). At the very least, stabilization of the running mean of survival (over replicate subsections) should be obtained as a measure of statistical adequacy.

Areal coverage

A *random* (as opposed to arbitrary) sample of area covered (square meters) per PU should be recorded until coalescence. The area covered by a PU may be measured by recording the average of two perpendicular width measurements (in meters) of the PU over the bottom. These numbers are averaged, divided by two, squared and multiplied by pi (i.e., pi*r^2) to compute the area of a circle and, in this case, the PU. This procedure tends to give a higher value than use of a quadrat, crisscrossed with string on 5-cm centers that is laid over the PU. In this case, the number of 5 X 5 cm grids (or half grids if there are only one or two shoots in the 5 X 5 cm grid) that have seagrass shoots are totaled and converted to square meters of cover for the PU. The quadrat method is more appropriate for seagrasses that propagate by long runners and do not form a clearly radial growth pattern (e.g., shoalgrass). The number of surviving PUs may then be multiplied by the average area per PU to determine the area covered on the planting site. After coalescence, the area of bottom covered should be surveyed using randomized grid samples (*Fonseca et al.*, 1985). Areal density is determined as the number of shoots per unit area of bottom, usually on a square meter basis, incorporating bare areas at that scale. These data may be used to assess persistence of the planting as well as total seagrass coverage.

Number of shoots

Random samples should be collected to measure the number of shoots per PU. The data from pre-coalescence surveys may be used to compare performance relative to other, local plantings by plotting the average number of shoots per PU over time. The data comparison may be statistical or visual (which often suffices to detect grossly different population growth rates). Shoot number is recommended over areal coverage as a measure of growth performance because shoot addition is a more accurate means of assessing the asexual reproductive vigor of the plantings. Also, areal coverage varies with the environmental setting of the planting. For example, in areas of high current, shoots may grow more densely. Without shoot number data, the patchy pattern in high current environments could be erroneously ascribed by inexperienced participants to poor planting performance instead of a natural pattern of growth.

Monitoring frequency

Survival, areal coverage, and number of short shoots per PU are straightforward measures, although they usually require snorkeling or SCUBA diving to make them (a factor that is surprisingly not considered, or equipped for, by many attempting these data collections). An individual can be trained to perform these counts in a few hours, and can count individual PUs in five to 10 minutes or less at early stages of the development of a planting project.

Monitoring of shoot numbers and area covered per PU should proceed quarterly for the first year after planting and semi-annually thereafter for two more years (a total of three years). After PUs begin to coalesce and the PU from which shoots originated can no longer be discerned, areal coverage data should be recorded and counts on a PU basis suspended.

Interpretation of monitoring data

The computations described above allow a direct comparison on a unit area basis of planted versus lost acreage. Success may then be based on whether the appropriate acreage of cover has been generated. This is a quantitative measure that can be equated with ecological function. If the planting project is for mitigation, then compliance may thereby be interpreted as both acreage generated and the unassisted persistence (no replanting) of that acreage over time (the recommended three-year period). Planting persistence is critical. If the planting does not persist, then the ecosystem has experienced a net loss and the project has not been successful. The population growth (shoot numbers over time) and coverage data may be compared periodically with published values (e.g., Fonseca *et al.*, 1987c) dependent on species and geographic region as a relative indicator of performance.

Although these recommendations may seem involved at the first reading, after a very few hours in the field this type of data collection becomes routine. The value of these data, however, go beyond mere scientific curiosity. As with any business proposition, it behooves all parties to have specific, quantitative criteria. Otherwise, cost projections cannot be made and cost overruns often follow. Time requirements and possible costs need to be clarified as much as practicable prior to the project. It is possible that little or no additional care will be required once the plants are established. But natural disturbance (animals, storms) and seasonal peaks and troughs in planting performance are expected, and periodic replanting can be beneficial to maintaining the investment. Because of the wide variety of planting sites and their conditions, many of the preceeding recommendations are by necessity often reduced to generalizations. Innovation in the planning and execution of a planting project is not only encouraged, but may be requisite.

Glossary

404 permit process: references section 404 of the Clean Water Act that provides the statutory authority to specific federal agencies regarding dredge and fill activities in the waters of the United States

arbitrary sample: a sample taken without regard to potential bias in the location, quality or quantity of the variable being sampled

areal coverage: coverage of the seafloor by seagrass expressed on a unit area basis

baseline acreage: the amount of habitat acreage at some past time that is used as a reference for computing subsequent changes in habitat abundance

bioturbation: the physical disruption of the seafloor and/or seagrass bed by the activity of any number of animals (e.g., rays, crabs, fish)

compensatory mitigation: the establishment of a wetland area for the purposes of offsetting a permitted loss of a like wetland

compliance: the degree to which stated project goals are attained

continuous cover: a seagrass bed with little or no open areas of unvegetated seafloor

coverage rate: the rate at which planting units colonize the seafloor expressed on a unit area basis over time

creation: in reference to wetlands, the conversion of persistent non-wetland area into a wetland, contingent upon the status of the non-wetland area having been persistent through 100 to 200 years

cultivated seagrass: seagrass plants that are generated under any one of several anthropogenically mediated techniques (e.g., tissue culture, micropropagation)

donor bed: an existing seagrass bed from which transplant material is harvested for planting elsewhere

dredge and fill: the act of dredging or filling of a habitat, particularly in reference to the management of this activity under sec. 404 of the Clean Water Act

enhancement: the increase in one or more values of all or a portion of an existing wetland by human activities, often with an accompanying decline in other wetland values

erosion scarp: a sometimes migrational focus of erosion in a seagrass bed that results in a scoured area, usually characterized by a precipice from which seagrass roots and rhizomes often protrude

growth strategies: the rate at which individual species of seagrass reproduce by either sexual means (seed production) or asexual means (tillering of rhizomes across the bottom accompanied by vegetative production of new short shoots)

habitat: an unspecified spatial scale that has physical, chemical and biological attributes conducive to the maintenance and propagation of biota

habitat functions: services provided to the ecosystem by a given habitat type (e.g., shelter, stability, refuge, nursery)

impact avoidance: avoidance of any alteration of an existing wetland

impact site: a site containing jurisdictional wetlands which is being, or is going to be altered by anthropogenic actions

in-kind: planting a wetland species that is the same as the one that was damaged

jurisdictional wetlands: wetlands under the management jurisdiction of a regulatory agency

long shoot: a collection of short shoots physically located on the same rhizome

lower depth limit: the depth to which seagrass can grow, which is usually determined by the amount and possibly the quality of available light

minimization: decreasing the degree of alteration of an existing wetland by modification of a project plan

mitigation: the actual restoration, creation, or enhancement of wetlands to compensate for permitted wetland losses

monitoring: collection of habitat attributes (e.g. depth, cover, species composition or planted seagrass growth) relative to assessment of pre-impact site conditions, planting site suitability, or planting performance

no net loss: a quantitative evaluation which compares habitat area replaced or conserved with the habitat area lost

off-site: planting of a wetland as some form of mitigation at a location not in immediate proximity to the physical location of the damaged wetland for which it is to compensate

on-site: planting a wetland on an area which has suffered a loss of a wetland habitat

out-of-kind: planting a wetland species that is not the same species as the one that was damaged or lost

patchy distribution: seagrass beds (areas where rhizomes overlap) and associated unvegetated bottom; either distinct, isolated patches of seagrass in a predominantly unvegetated seafloor or meandering patterns of unvegetated bottom in a predominantly vegetated area

peat pot: in reference to a seagrass transplanting technique in which plugs of seagrass are removed and placed into small, commercially available cups constructed of compressed peat; the plug and peat pot container are then planted in the seafloor

permitting agency: a resource management agency (e.g., state, federal) that has statutory authority for issuing or commenting on permits dealing with wetland modifications

phenotype: the sum total of observable structural and functional properties of an organism

pioneering species: a species of seagrass with a growth strategy that enables it to rapidly colonize unvegetated seafloor

planting performance: attributes of a planted area which can be used as indicators of project success; e.g., planting unit survival, planting unit population growth and coverage rate

planting ratio: the ratio of planted, and eventually, persistent seagrass acreage to the amount of acreage lost in a given project

planting unit(s): an individual core, plug, staple, peat pot, sod, etc., and the associated plant material used in a planting operation

plugs: in reference to a seagrass planting technique in which hollow tubes are used as a coring device into a seagrass bed, thereby harvesting the sediment "plug" in the tube with the associated seagrass

propeller scarring: typically a long, linear furrow excavated in the bottom as the result of operating vessels in water depths shallower than the draft of the drive unit (propeller); results in excavation of seagrass

PU: planting unit

random sample: a sample taken such that each sample unit has an equal (unbiased) probability of being selected

restoration: returned from a disturbed or totally altered condition to a previously existing natural, or altered condition by some action of man; refers to the return of a pre-existing condition

rhizome: (sensu Websters' Collegiate Dictionary) a somewhat elongated, usually horizontal plant stem which produces shoots above and roots below and is distinguished from roots in possessing buds, nodes and scale-like leaves

rhizome apical: the meristematic region at the terminus of a long shoot that gives rise to further rhizome growth and differentiates to give rise to short shoots

salvage operation: transplanting seagrass from an area where activities are planned that will destroy that seagrass

sediment resuspension: the transfer of sediment from a resting position on the seafloor to the water column as the result of some external action such as wind waves, tidal currents, or a vessel's propeller(s)

short shoot: an individual meristem located on a long shoot which produces leaves and roots

site survey: a quantitative assessment of the amount of plant material to be disturbed, its distribution and the physical conditions at impact and planting sites prior to initiating a project (see also monitoring)

slow release fertilizer: fertilizer specifically designed to leach nutrients over a prescribed period of time at a given temperature

staple: in reference to a seagrass planting technique in which plants are washed free of sediment and typically are attached to a U-shaped metal bar (staple), which is then inserted points down into the sediment, pinning the seagrass to the seafloor

success: although the definition of this term may be changed with the goals of the project at hand, a broadly applicable definition is as follows: the unassisted persistence of seagrass coverage for a prescribed period of time (suggested minimum of three years)

turbidity the degree of opacity of the water column as a result of dissolved and suspended material in the water column

unassisted persistence: seagrass beds maintained by natural recruitment but not assisted by any deliberate anthropogenic manipulation

unvegetated seafloor: the portion of the estuarine floor which is not colonized by rooted submerged aquatic vegetation

water transparency: inverse of turbidity

wild stock (stands): naturally occurring seagrass beds

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Appendix A

Characteristics of Species

(Alphabetical order by common name)

The following descriptions of species refer to the illustrations of the six Gulf species in Figure 1.

Manatee grass (*Syringodium filiforme*)

This species is easily distinguished from all the other seagrass species in the Gulf. It is nearly cylindrical. Its long erect blades are *ca.* 1 to 3 mm in diameter and there are usually only two leaves per shoot. These beds often accumulate a large understory of unattached macroalgae. The rhizome system varies in depth, between 1 and 10 cm. Flowering produces extensive branching that extends up into the water column, similar to widgeongrass but not as extravagant. Rhizomes may extend into the water column with attached shoots as described for shoalgrass, again presumably as a means of producing vegetative propagules (as opposed to seeds). As with shoalgrass, these propagules make excellent transplanting stock with no apparent disruption of the donor bed.

Paddle grass (*Halophila decipiens*)

This species is very small, usually standing no more than 5 cm tall. Its oval blades resemble paddles, hence its common name. The blades occur in pairs and are very thin, approximately 1 cell thick, and appear translucent. The rhizomes occur very near the sediment surface and are often exposed to the water column. The plants are among the most fragile of the seagrasses and can be easily uprooted. Natural stands of paddle grass can, however, be an effective barrier to erosion (Fonseca, 1989b). These plants require less light than most seagrasses and can be found in shallow, turbid areas, under docks, or at depths up to 40 m in clear, tropical waters. This plant can be mistaken for some algae unless examined carefully. The presence of veins in the leaves will serve to distinguish it from algae. This species produces many seeds, which often is the only way a local population is preserved over the winter when the leaves, roots, and rhizomes die. The seeds are extremely small, approximately similar in size to a grain of table salt. Despite extensive acreage of seasonal beds of this species in Florida and perhaps elsewhere, little is known about its functional role in the coastal ecosystem.

Shoalgrass (*Halodule wrightii:* contrast with widgeongrass)

This species was once classified under the genus *Diplanthera*; references from earlier than 1975 often refer to this species under that genus. It has a lower depth limit equal to turtlegrass and manatee grass. It also can occur in very shallow water and it is noted for its relative tolerance to desiccation once rooted. It often forms large pancake-like patches reaching 30 m in diameter or extensive meadows on shallow shoals and flats, experiencing regular exposure at low tides (the basis for its common name). The fine (1 to 3 mm width) blades occur in groups of two to four on a shoot and vary in length according to depth as does turtlegrass. Blade lengths range from as short as 5 cm to more than 40 cm. This species forms very dense beds, with upwards of 5,000 shoots per square meter (although 11,000 can occur; pers. obs). Flowers are difficult to locate as they occur on the base of the shoots near the sediment surface. Rhizomes are fairly shallow, rarely being deeper than 5 cm, although roots may extend for 25 cm or more. Rhizomes may extend into the water column with attached short shoots, which appear to be a form of vegetative propagule formation. These rhizomes may be easily harvested and are efficiently transplanted with the staple method.

This species can easily be confused with widgeongrass. Four visual clues separate them:

1. Widgeongrass produces extensive flowering stalks often reaching a meter in length, with numerous seed clusters resembling miniature rattlesnake rattles, while flowers in shoalgrass are rarely seen.
2. The blade tip of shoalgrass forms a miniature three-point crown, with the two leaf margins and central vein of the leaf forming the points. Widgeongrass blades taper to a single sharp point.
3. Shoalgrass rhizomes are usually very straight and white while widgeongrass rhizomes are often somewhat zigzagged when viewed from above and may be green or white.
4. Shoalgrass has two roots per node on the rhizome while widgeongrass has one root per node.

Star grass (*Halophila engelmanni*)

Like its relative paddle grass, star grass is a very small plant, rarely exceeding 10 cm in height. The leafy stalks form a rosette of *ca.* six leaves, resembling a star, which is the basis of its common name. Distribution and function is currently thought to be similar to paddle grass.

Turtlegrass (*Thalassia testudinum*)

This species is one of the most well-known seagrasses in the Gulf. It is a favorite food of the endangered green sea turtle, hence its common name. Its broad (often > 1 cm wide) deep green, strap-like blades (usually three to a plant but often five or more) cannot easily be mistaken for any other marine submerged macrophyte in the Gulf. Leaf length of the plants depends on water depth (as is the case with most seagrasses) and varies from *ca.* 10 to 75 cm. The leaves emerge from the sediment at the top of a stem that rarely protrudes above the sediment surface. The thick, fibrous rhizomes from which the individual shoots originate are often located in excess of 20 cm into the sediment. This species develops flowers that emerge from the sediment next to the short shoot. Once fertilized, a round seed the size of a small acorn will be produced. Seeds have been successfully used in planting projects. This species is noted for its longevity (often >10 years for an individual shoot) and the dense, extensive stands.

Widgeongrass (*Ruppia maritima*: contrast with shoalgrass)

This species is a favorite food of migratory waterfowl, a fact on which its common name is based. This species does not usually form a rhizome mat as dense as that of shoalgrass, but does much to stabilize the bottom. This species is set apart from all other seagrasses in that it can grow in both fresh water and hypersaline conditions (> 70 ppt). See shoalgrass for further description and contrast.

Appendix B

Partial List of Equipment

Some sites may be accessible only by boat. Local knowledge of wind, tide and navigational hazards should be obtained prior to operations. A complete list of emergency numbers and emergency procedures should be determined in advance. Reliable, seaworthy vessels that can work in a range of sea conditions and water depths should be used. More than one vessel type might be required. If you are not fully knowledgeable in these areas and do not possess basic training in navigation and seamanship, retain trained personnel as boat operators, divers, etc.

Staple method

- Paper coated twist ties (e.g., tomato plant tie-up material)
- Dive knife (or similar tool for loosening the bottom to insert the staple)
- Mesh float buckets (for holding plants washed free of sediment)
- Site markers (stakes, buoys, etc. Three-quarter-inch diameter schedule 40 PVC pipe (white) is relatively inexpensive, comes in 10-foot lengths and can be easily driven into the sediment although it must be cleaned out between uses).
- Waterproof tape measures (100 m variety)
- Lead core lines with ribbons on plating intervals if precise spacing is desired or visibility is so poor that a means of orientation is required at depth (line is manufactured for gill nets, survey ribbon must be added)

or

- Polypropylene line with ribbons may be floated on the surface as a planting guideline for surface-oriented (non-diving) operations.
- Snorkeling or SCUBA equipment (certified divers only).
- If SCUBA diving is required, develop and rehearse a Dive Accident Management Plan. Follow emergency procedures as recommended by recognized safety groups such as the Divers Alert Network (DAN).
- Tide tables and updated weather forecast
- First aid kit including sun screen and insect repellent
- Redundant communications equipment
- Appropriate clothing for exposure cannot be overstated. Equipment such as wet suits, wool clothing and foul weather gear that can be worn in the water as well as a wind breaker. Waders may be preferred by some people but since seagrass planting requires much bending over, it is not unusual to overtop waders.
- Warm or cold fluids (depending on season), fresh water, and high energy foods
- Polarized sun glasses (enhances visual penetration of the surface)

Peat pot method

All of the same operational equipment as required by the staple method except for the first four items. These should be replaced by the following:

- Peat pots (3" square)
- Plugger (same size as peat pot)
- Tree planting bar
- PVC (or equivalent) float collars to support *ca.* 30 peat pots in a tray
- Durable plastic trays to contain *ca.* 30 peat pots
- Heavy (*ca.* 10 ga.) wire mesh to fit over peat pots in tray to prevent them from floating out as any air pockets are displaced by water

Core tube method

All of the equipment required by the staple method except for the first four items. Replace with as many core tubes as the transport vehicle will hold.

Surveys

- Transit
- Meter sticks
- Waterproof tape measures (100 m variety)
- Random number table
- Writing tablets (photocopiable underwater paper on clipboards with prepared data collection sheets are useful). Pencils or grease pencils tethered to the tablet with a generous length of surgical tubing is inexpensive.

(**Optional** – Depending on survey technique)

- Quadrat: 1 x 1 m 1" PVC sand-filled frame with parachute cord (thin braided nylon line) on 25 cm intersections.

Appendix C

Suggested Minimum Components of Proposals and Reports

- A. Project Proposal
  - 1. Identification of goals
    - a. compensatory mitigation or restoration
    - b. specify replacement ratio and final acreage
  - 2. Description of impact site survey methodology
  - 3. Site selection criteria and list of sites
  - 4. Location and availability of donor material
  - 5. Planting methodology
  - 6. Spacing and spatial arrangement on site
  - 7. Monitoring specifications
    - a. identification of variables and methods of collection
    - b. monitoring and reporting frequency and duration (suggest minimums of 4 times in year 1, 2 times in year 2, and annually thereafter; this frequency allows implementation of Item 8)
    - c. monitoring interpretation criteria
  - 8. Specify criteria for remedial planting
  - 9. Specify criteria for success (i.e., acreage of seagrass cover to be generated [1b], species, duration of unassisted persistence)
  - 10. Specify duration of responsibility and consequences of non-compliance with Items 1-9
- B. Time Zero Report
  - 1. Results of impact site survey and statistical relevance of the survey methodology
  - 2. Documentation of implementation as compared to the descriptions of Items 1 through 6 above
- C. Progress Reports
  - 1. Results of monitoring as described in Section A, Item 7, above
  - 2. Identify and document any remedial action taken
  - 3. Provide best professional estimate of likelihood of meeting Section A, Item 9
- D. Final Project Report
  - 1. To improve subsequent projects, review operational errors/shortcomings in the context of the original project proposal
  - 2. Identify and document compliance with all stated requirements, with particular attention to Section A, Items 1a and b, 7b and c, 8, 9, and 10

Appendix D

Recommendations for Further Reading

The following community profiles on seagrass published by U.S. Fish and Wildlife Service:

Phillips, R.C. 1984. The ecology of eelgrass meadows in the pacific northwest: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-84/24. 85 p.

Thayer, G. W., Kenworthy, W. J., Fonseca, M.S. 1984. The ecology of eelgrass meadows of the Atlantic coast: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-84/02. 147 p. Reprinted 1985.

Zieman, J.C. 1982. The ecology of the seagrasses of south Florida: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-82/25. 158 p.

Zieman, J.C., Zieman, R.T. 1989. The ecology of the seagrass meadows of the west coast of Florida: a community profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.25). 155 p.

Specific readings on seagrass restoration and management.

Churchill, A.C., Cok, A.E., Riner, M.I. 1978. Stabilization of subtidal sediments

Florida Department of Natural Resources. 1987. Proceedings of the symposium on subtropical-tropical seagrasses of the southeastern United States. Fl. Mar. Res. Rep. No. 42. (Entire document).

Fonseca, M.S., Kenworthy, W.J., Thayer, G.W. 1982. A Low-cost Planting Technique for Eelgrass (*Zostera marina* L.). U.S. Army Corps of Engineers, Coastal Engineering Tech. Aid No. 82-6.

Fonseca, M.S., Kenworthy, W.J., Cheap, K.M., Currin, C.A., Thayer, G.W. 1984. A low-cost transplanting technique for shoalgrass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*). U.S. Army Corps of Engineers, Instruction Rep. EL-84-1.

Fonseca, M.S., Kenworthy, W.J., Thayer, G.W., Heller, D.Y., Cheap, K.M. 1985. Transplanting of the seagrasses *Zostera marina* and *Halodule wrightii* for sediment stabilization and habitat development of the east coast of the United States. U.S. Army Corps of Engineers Technical Report EL-85-9.

Fonseca, M.S., Thayer, G.W., Kenworthy, W.J. 1987c. The use of ecological data in the implementation and management of seagrass restorations. p. 175-187 *In* Durako, M.J., Phillips, R.C., and Lewis, R.R. (eds.), Proc. Symp. Subtropical-tropical Seagrasses of the Southeastern U.S. Fl. Mar. Res. Pub. No. 42.

Fonseca, M.S. 1989a. Regional analysis of the creation and restoration of seagrass systems. p. 175-198. *In* Kusler, J.A. and Kentula, M.E. (eds.), Wetland Creation and Restoration: the status of the science. Vol. I. Regional Reviews. EPA/600/3-89/038a. Environ. Res. La., Corvallis, OR.

Fonseca, M.S. 1992. Restoring seagrass systems in the United States. p. 79-110. *In* Thayer, G.W. (ed.), Restoring the nation's marine environment. Maryland Sea Grant College Pub. UM-SG-TS-92-06. 716 p.

Lewis, R.R. 1987. The restoration and creation of seagrass meadows in the southeast United States. p. 153-173 *In* Durako, M.S., Phillips, R.C. and Lewis, R.R. (eds.), Proc. of the Symp. on Subtropical-Tropical Seagrasses of the Southeastern United States. Fl. Mar. Res. Publ. No 42.

Lewis, R.R. 1989. Wetlands restoration/creation/enhancement terminology: suggestions for standardization. p. 1-8 *In* Kusler, J.A. and Kentula, M.E. (eds.), Wetland Creation and Restoration: the status of the science. Vol. II. Perspectives. EPA/600/3-89/038b. Environ. Res. Lab., Corvallis, OR.

Phillips, R.C. 1982. Seagrass meadows. p. 173-202 *In* R.R. Lewis (ed.), Creation and restoration of coastal plant communities. CRC Press, Boca Raton, FL.

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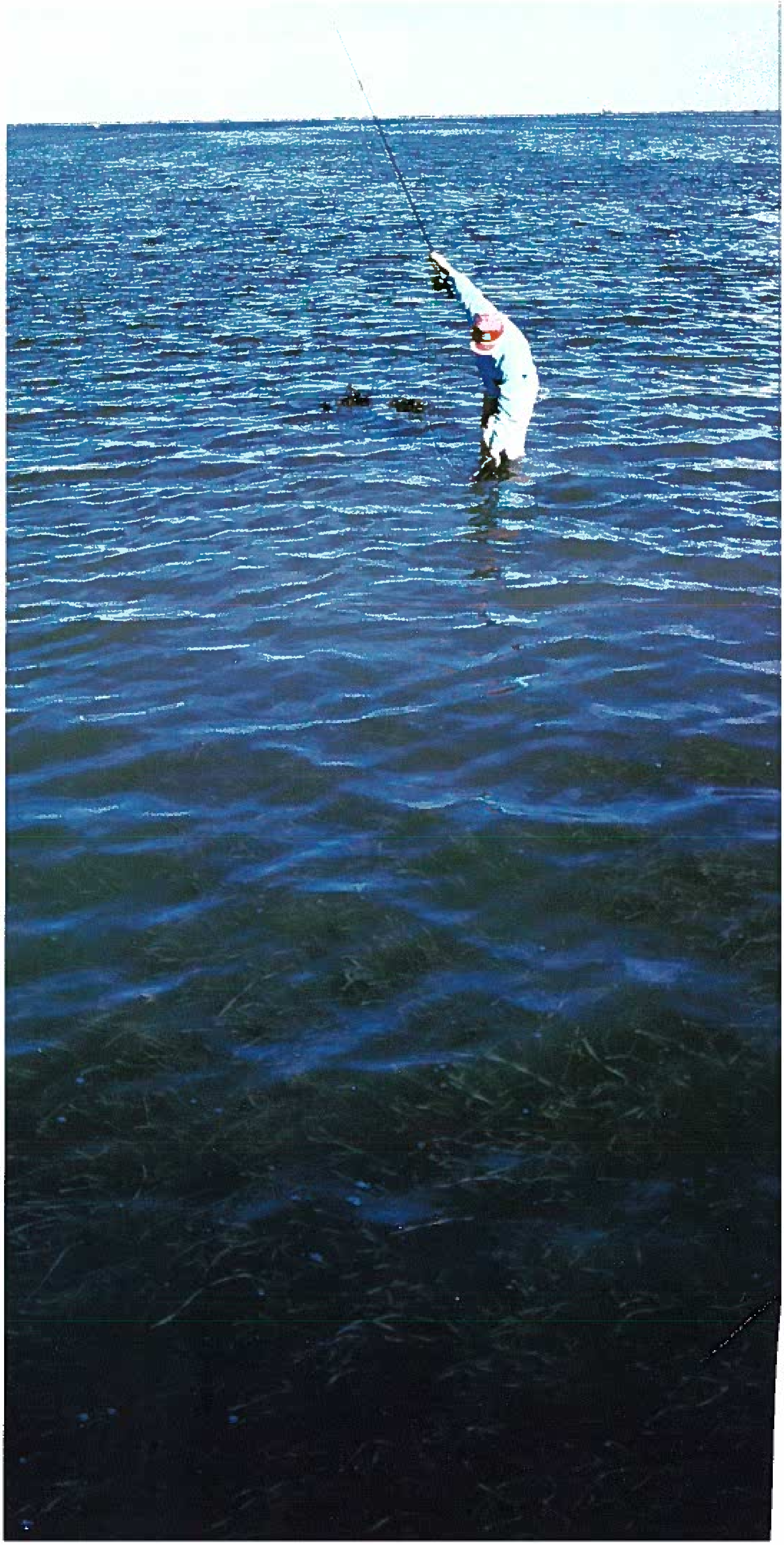

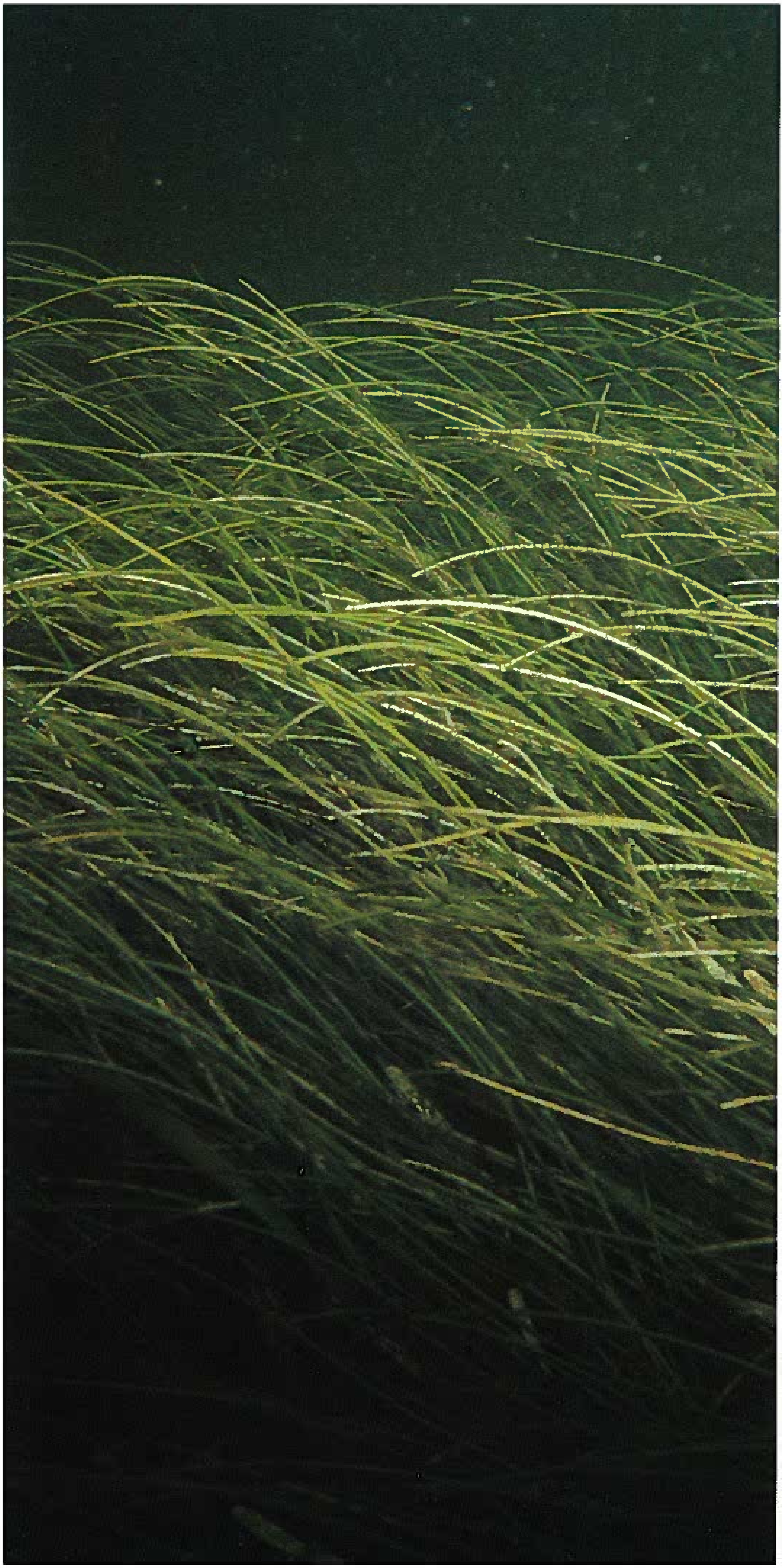

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