

TRANSPLANTING *THALASSIA TESTUDINUM* AS A METHOD OF STABILIZING UNDERWATER CULTURAL RESOURCES IN BISCAYNE NATIONAL PARK, FLORIDA

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STATEMENT OF PROBLEM

The Fowey is a valuable submerged cultural resource because of its age and unique history. Park service archeologists want to preserve it *in situ* until some time in the future when technology improves, and the excavation of the wreck can be done with minimal destruction. *In situ* preservation requires stabilization of the remains of the wreck, preferably beneath the sediment surface to reduce aerobic decomposition. At present, the wreck lies in an area between a stable seagrass system and an area of historically unstable, shifting sands, the Legare anchorage. It is believed that prior to excavation, the stable seagrass area extended over the wreck. The objective of this paper is to outline possible methods for restoring the seagrass coverage over the wreck. To achieve this objective, I will: 1) describe what is known about the history of seagrass on the site; 2) briefly review the ecology of seagrass in the subtropical region of South Florida; 3) discuss transplanting techniques and general factors affecting success of seagrass transplants; and, 4) outline specific factors affecting success or failure of seagrass transplants stabilizing the Fowey site in particular.

HISTORY OF SEAGRASSES ON THE WRECK SITE

The existence of dense seagrass cover over the Fowey site previous to the disturbance and excavation of the site by treasure salvors is alluded to in nearly every account of the site history (Table 1; Wild •unknown, Timant et al. 1982, Skowronek 1987). However, the extent of coverage and the density and composition of the historical bed is unknown, as disturbance was severe when the wreck was first located by the National Park Service. If some record of this grassbed could be established from historical areal photographs, it would greatly increase confidence that the site could support dense and stable seagrass communities. As it stands, we do not know if the edge of the unstable Legare Anchorage migrates over the site naturally as a function of storm frequency and intensity.

SUMMARY OF TRANPLANTING EFFORTS IN 1983

One line of evidence that supports the potential for the site supporting stable seagrass, at least in the short term, is the success of a previous transplanting attempt; however, this success was somewhat limited. During the 1983 summer field season, archaeologists excavated several portions of the Fowey site. Excavated areas were carefully backfilled with sediment, then a thin layer of sediment was fanned over all exposed wood. After burial, two methods of site stabilization via passive burial were attempted, planting with both artificial and natural seagrasses. These studies were described by Skowronek et al. (1987) and Wild (from background info) and are summarized below.

The artificial seagrass used was called Seascape; it is composed of "shoots" composed of several inert fiberglass tubes, with styrofoam attached to the tips of these

"fronds" to keep them floating above the benthos. The sand-filled fronds are heavy, and keep the shoots in place. These units were used successfully to prevent erosion in a "high energy" area at Cape Hatteras National Seashore. Need to determine what high energy means here compared to Fowey Site. At the site, the units were placed parallel to the prevailing tidal-induced current that was thought to provide most of the erosional force at the wreck site. Thus, the Seascape was to slow the particulate-laden current causing sand to drop and accumulate. However, encrusting organisms quickly colonized the surface of the artificial grass, weighing it down, and causing the fronds to lie on the benthos. The investigators attributed the greater abundance of epiflora and fauna on seascape fronds at the Fowey site compared to the site in South Carolina to the relatively low energy environment at the Fowey site. However, current speeds at the two areas were not directly compared. An alternative hypothesis may be that organisms in tropical systems grow faster and accumulate biomass more quickly. In addition, they may contain more encrusting forms that deposit calcium carbonate to defend against herbivores, and weigh more than their counterparts in temperate zones. Finally, the planting units were placed to counter the prevailing tidal current; Tilmant et al. (1982) found that the factor that most affected sediment transport was not currents, but wave surge. Thus the orientation of the planting may not have been optimal.

Several methods of transplanting two species of natural seagrasses were attempted at the Fowey site after the 1983 field season (Wild ?). All transplanting experiments were conducted on an area of bare sand next to the actual wreck site; this area did not appear to have been disturbed by the prop washes of the salvors. However, if this site was suitable for seagrasses, the question arises as to why in the absence of disturbance, the area was devoid of seagrasses at the time of the experiments.

A pilot experiment was conducted using "sprigs" of both Thalassia testudinum and Syringodium filiforme. Sprigs consisted of at least three shoots stapled together (ask Richard... with rhizomal meristem?). Syringodium filiforme was used because it was considered to be a hardy species that colonizes new areas while Thalassia testudinum is the dominant species in this area of the Park. All sprigs died shortly after planting because they were anchored into the sediment with galvanized nails that oxidized and killed the plants.

In the next experiment sprigs, plugs (intact cores containing plants and sediment), and seedlings of both species were planted. Within three weeks, sprigs and seedlings of both species suffered complete mortality; plugs showed high rates of survival.

However, after 2 months the remainder of these transplants had died. Death was attributed to insufficient light (seedlings and cores were taken from shallower donor beds), predation (?? what do they mean by predation?? grazing??bioturbation), and uprooting by storm surges. A second planting of Thalassia testudinum sprigs from a donor bed at a similar depth to the planting site was successful, both surviving the initial period of adjustment to the transplant site, and expanding the areal coverage of shoots. Unfortunately, before the seagrass plantings had coalesced into a stable bed, the area was again disturbed by salvors using prop wash diverters. However, this study suggests that if the area that was transplanted could be protected from storm and salvor disturbance, it may be able to support a viable seagrass bed.

Unfortunately, we do not know if the site needs long-term protection to develop and maintain a dense seagrass bed. It is possible that, unprotected, this area receives enough periodic (winter storms) or episodic (tropical storms and hurricanes) disturbance to only maintain seagrass beds that are extremely patchy in time and space.

ECOLOGY OF SEAGRASSES IN SUBTROPICAL REGIONS

COMMUNITY COMPOSITION

Soft-bottom habitats of South Florida are dominated by extensive benthic communities of seagrass and associated epiphytes (Zieman et al. 1989). Seagrasses are adapted to thrive in low-nutrient, high-light environments (Larkum et al. 1989), and seagrass communities provide food, habitat, and nursery grounds for many fish and invertebrates, including turtles, shrimp, and lobster (Allen et al. 1980, Klima et al. 1986, Thayer and Chester 1989). The seagrass community in the South Florida region is structurally and functionally complex. In general, the dominant species of seagrass is Thalassia testudinum, although Halodule wrightii and Syringodium filiforme may co-occur or dominate in some areas. The seagrass community also includes different functional forms of algae (sensu Littler and Littler 1980).

Macroalgae, such as the rhizophytic algae in the genera Penicillus, Halimeda, and Caulerpa, may be attached to the benthos. Both micro- and macroalgae, especially filamentous or sheet-like reds or greens, may grow attached to seagrass blades.

Although Thalassia testudinum, Halodule wrightii, and Syringodium filiforme can co-occur in sandy habitats throughout Florida and the Caribbean, one species is usually dominant in any given area (Dawes et al. 1985, Williams 1990, Short et al. 1990). This dominance is thought to be driven by a combination of physical factors and biological interactions. The relative importance of biotic versus abiotic factors in controlling the distribution and abundance of each photosynthetic member of the seagrass community is still unknown, as is the importance of interactions between these groups of benthic primary producers. In general, it is believed that T. testudinum

is a "climax" species and dominates when biological factors control community structure (Williams 1990), S. filiforme is tolerant of low nutrient supply (Williams 1990), and H. wrightii is an early successional or disturbance-mediated species, dominating when physical factors are extreme (Zieman et al 1989).

The seagrass community adjacent to the Fowey site is dominated by Thalassia testudinum and Syringodium filiforme, but not Halodule wrightii. H. wrightii is usually dominant in bays or nearshore areas where salinities vary greatly from oceanic values (Conover 1964, McMillan and Moseley 1967, Montague 1989, Dunton 1990) and extreme deviations in salinity are probably rare at the Fowey site; for this reason, H. wrightii will not be considered further as a candidate for site stabilization.

RELATIONSHIPS TO ENVIRONMENTAL VARIABLES

Some seasonal trends in productivity and biomass of Thalassia testudinum have been attributed to variation in temperature. T. testudinum tends to have the lowest biomass and the highest productivity in spring and early summer and maximum biomass but minimum productivity in fall (Tomasko and Dawes 1990, Dawes et al. 1985).

Seasonality seems to be strongest on the West Coast of Florida (e.g., Tampa), where winter temperatures can drop significantly. Dawes et al. (1985) found that T. testudinum loses aboveground biomass at temperatures below 16°C. In Florida Bay, high temperatures combined with other stresses have been implicated recently in extensive seagrass die-off (Robblee et al. 1991, Zieman pers. comm.). No information on temperature dependence or seasonal variability of the other two species of seagrass was found.

There is substantial evidence that light is an important factor controlling seagrass productivity and distribution (Williams 1987, Dawes and Tomasko 1988, Dunton 1990). Fourqurean and Zieman (1991) established the relationship between light and photosynthesis for Thalassia testudinum. T. testudinum has a typical Photosynthesis vs Irradiance curve, with a $P_{\max}$ of $200 \mu\text{g O}_2\cdot\text{g}^{-1}\cdot\text{min}^{-1}$, saturation occurring at $425 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$, and no photoinhibition at high light intensities; the compensation point is approximately $15.1\text{-}15.7 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$. Williams (1987) found that light saturation levels for Syringodium filiforme and T. testudinum were similar. Dunton and Tomasko (1990) found lower light saturation levels, just over $300 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$, for Halodule wrightii. However, Photosynthesis vs Irradiance curves for seagrasses may vary with depth and season (Drew 1978, Dawes and Tomasko 1988, Dunton and Tomasko 1990). In addition, there is evidence that suggests that some seagrasses require a critical minimum length of time each 24 hrs when photosynthetic photon flux density reaches or exceeds the photo-saturation level (Dennson and Alberte 1985). Because dense T. testudinum beds already exist adjacent to the Fowey site, it can be assumed that light conditions (both intensity and duration) are suitable. However, if light availability is near the lower threshold of the critical value, then establishment and growth of transplanted plants may be very slow.

Unlike many other aquatic primary producers, seagrasses have access to nutrients that accumulate in the sediments (Larkum et al. 1989); many hypothesize that this ability enables seagrasses to dominate in tropical to subtropical regions characterized by low water column nutrient supplies. However, each species may be favored under different nutrient conditions. There is correlative work showing that Syringodium filiforme generally occurs in oceanic environments, with lower sediment nutrients than bays or estuaries associated with continents (Short et al. 1985, 1990). *** Check this*** Williams (1990) found that S. filiforme colonized newly opened bare spots within a

seagrass bed dominated by Thalassia testudinum. She hypothesized that S. filiforme is favored when nutrient concentrations in the sediments are very low, and that S. filiforme is replaced by T. testudinum after nutrients build up in the sediment. In another experiment testing the effect of a natural source of fertilizer on a seagrass bed dominated by T. testudinum, addition of bird excrement to semi-enclosed areas of Florida Bay resulted in an accumulation of sediment pore water phosphate and ammonium (Powell et al. 1989). After one yr of enrichment, leaf productivity and standing crop of both T. testudinum and Halodule wrightii increased; however, after three yr H. wrightii replaced T. testudinum as the community dominant. This work and others (Pulich 1989, Powell et al. 1989) suggests that T. testudinum is favored through a wide range of sediment nutrient concentrations, but is replaced by H. wrightii when sediment nutrients are very high. It has been hypothesized that T. testudinum cannot tolerate the anaerobic conditions that commonly occur in nutrient-rich sediments (Fong and Harwell 1994), so very high nutrients favor productivity of H. wrightii, a stress-tolerant opportunist (Pulich 1989).

There is evidence from both correlative field surveys and field experiments that suggests phosphorus (P), not nitrogen (N) limits seagrass productivity in tropical and subtropical carbonate sediments. Carbonate geochemical processes such as P-adsorption have been measured in sediment cores taken from tropical carbonate environments; these processes may deplete phosphate pools in sediment pore water (Kitano et al. 1978, Short et al. 1985, Morse et al. 1987). In addition, field measurements of pore water nutrients have shown that phosphorus is in much lower concentration than inorganic nitrogen (Short et al. 1985, 1990). Finally, in a manipulative nutrient enrichment experiment, addition of phosphorus alone greatly stimulated primary productivity of Syringodium filiforme in the Bahamas (Short et al. 1990). However, in this experiment, addition of nitrogen alone caused some

stimulation, and addition of both nutrients had a synergistic effect. Thus, it may be necessary to consider both N and P concentrations in the sediments to assess the potential for successful seagrass transplanting.

Sediment nutrient concentrations have not been measured at the Fowey site, but they probably are similar to other areas of the Florida Reef Tract. Szmant (*** Alina, could I use the numbers you generated, here? is it published anywhere?) found that pore water nutrient concentrations in mid-shelf stations off of Key Largo were very low, ranging from $?\mu\text{M}$ P and $?\mu\text{M}$ N. ** These values are may be too ??? low to support a dense bed of Thalassia testudinum.

ECOLOGICAL FUNCTIONS

Seagrass communities have several ecological functions. Seagrasses add structural complexity to areas with otherwise homogeneous substratum and therefore provide habitat and refuge from predation for juvenile fin and shell fish (Petersen 1918, Thayer et al. 1975, Allen et al. 1980, Thayer et al. 1984, Klima et al. 1986, Thayer and Chester 1989, Zieman and Zieman 1989). Although this important ecological function has been well established, it is not the role for seagrass proposed for the Fowey site, and thus will not be discussed further.

Seagrass beds are highly productive (Table 2), adding energy to the base of the food chain as well as stimulating detritus-based decompositional pathways for energy flow. Seagrasses of subtropical to tropical regions have varying rates of productivity (Table 2) and biomass accumulation (Table 3) under different physical and chemical regimes; understanding these differences may help managers select the species that

should be used for site stabilization. Productivity rates for seagrasses are reported in several forms, including dry wt·area⁻²·day⁻¹, wt·wt⁻¹ (% increase), and leaf elongation. For Thalassia testudinum, Williams (1988) found maximum productivity up to 27,000 mg dry wt·m⁻²·day⁻¹ in pristine areas of the Virgin Islands, and Fourqurean and Zieman (1991) found maximum biomass to be 470,000 mg dry wt·m⁻² in Florida Bay (Table 2). Powell et al. (1989) found that Halodule wrightii in Florida Bay can produce as much as 16,360 mg dry wt·m⁻²·day⁻¹, with a maximum standing crop of 150,000 mg dry wt·m⁻². Maximum production was 6,300 mg dry wt·m⁻²·day⁻¹ and maximum biomass 190,000 mg dry wt·m⁻² for Syringodium filiforme in the Bahamas (Short et al. 1985). Thus, the hierarchy for productivity rate is T. testudinum > H. wrightii > S. filiforme and for maximum biomass is T. testudinum >> S. filiforme ~ H. wrightii. This relationship establishes an environmental carrying capacity for seagrass, and indicates that when conditions are maximal for T. testudinum, it is the best competitor. Thus, if these productivity and biomass accumulation hierarchies are used as the sole criterion, it would seem that T. testudinum may be the effective species for stabilizing the Fowey site. However, the productivity rates and biomass estimates given in Tables 1 and 2 are maximum values for mature, dense seagrass beds; as discussed later, rates for sparsely distributed transplants are very different.

The most important ecological function of seagrass communities in light of the proposed use at the Fowey site, is that an established seagrass bed may act to stabilize and deepen the sediment layer covering the shipwreck. Seagrasses act to reduce water motion, and therefore enhance sediment accumulation, add to sediment stability, and thus provide some measure of erosion control (Ginsberg and Lowenstam 1958, Orth 1977, Fonseca et al. 1982, 1983, Ward et al. 1984, Fonseca and Fisher 1986). In an experiment that varied water velocity (5 to 30 cm · s⁻¹), water depth and plant density in a flume, the effectiveness of tropical seagrasses in

inhibiting sediment movement was ranked Thalassia testudinum > Halodule wrightii > Syringodium filiforme (Fonseca and Fisher 1986). This study confirmed that T. testudinum provided the greatest protection of the sediment surface from erosional forces, and S. filiforme the least. It was concluded that larger, strap-bladed seagrasses were more effective at preventing erosion due to their denser canopies and deeper root structures. However, in a subsequent study, water velocities of 43 cm · s⁻¹ did not erode *Halophila decipiens* plants after several minutes (Fonseca 1989). Thus *Halophila decipiens*, a small banded and shallowly rooted species, was able to withstand water velocities equivalent to those withstood by larger species of seagrass, suggesting that the ability to resist erosion may not be a simple function of plant morphology.

Once established, dense seagrass beds may be very stable. A survey of the seagrasses fringing the western edge of Biscayne Bay in Biscayne National Park two months after Hurricane Andrew revealed there was no detectable disturbance of the root and rhizome structure (Fong, unpubl. data), despite the considerable forces generated by wave driven winds and storm surge. It is possible that the above ground biomass was removed and then re-sprouted in the interval between storm and survey, as each of the short shoots only had 2 - 3 blades. On the other hand, Meeder et al. (1994) found considerable localized disturbance to seagrass meadows on the leeward side of Totten Key, one of the chain of islands that form the eastern edge of Biscayne Bay. They hypothesized that abnormally high bottom currents were generated during the Hurricane at this location. Most of the damage to the seagrass bed was by removal of large (up to 8 m wide) D-shaped divots of grass complete with roots and rhizomes, often coalescing, and resulting in removal of sediments and increased water depth. In a larger scale survey of Biscayne Bay (Wanless and Tedesco, pers.

comm... check on this!!) found that damage to the seagrass beds was limited to areas where scouring due to storm surge was focused??

Although established seagrass beds are usually considered stable, different species have varying abilities to survive disturbances such as blow outs and anchor scars. Thalassia testudinum does not readily grow into areas of bare sand that have been exposed by either natural or anthropogenic damage (Patriquin 1975, Zieman 1976); bare areas are more frequently colonized by Syringodium filiforme. Williams (1990) suggests that S. filiforme is a pioneer species in areas where sediment nutrient concentrations were low, acting to nutrify the sediments for later successional species like T. testudinum. This suggests that, although T. testudinum may be a better sediment stabilizer once established, a better candidate for transplanting may be S. filiforme, as the presence of this species may enhance the ability of T. testudinum to colonize and spread.

Some evidence exists that sparse or patchily distributed seagrass beds may be a natural occurrence, and not a necessarily function of successional age or anthropogenic disturbance. Several transplanting projects have selected sites with patchy seagrass cover using the rationale that the general area is clearly suitable for seagrasses, and transplanting to "infill" empty patches would have a high degree of success. However, Fonseca et al. (1983) correlated seagrass meadow form and patchiness with current regime. They noted that as maximum current velocities became higher, meadows became more patchy. Conversely, Fonseca et al. (1988) observed sites where wave energy was reduced, and patchy seagrass beds coalesced into continuous cover. In a review (Fonseca et al. 1988), it was concluded that all attempts to fill patchy areas with transplants failed to decrease patchiness at a site. This is a major concern for the success of the transplanting at the Fowey site.

Clearly the area is subjected to episodic or periodic wave surge events, even in the season of minimal wave action, as evidence by the formation of sand waves in the summer of 1981 (Tilmant et al. 1982).

SEAGRASS TRANSPLANTING TECHNIQUES AND FACTORS AFFECTING SUCCESS

TRANSPLANTING TECHNIQUES

Often Thalassia testudinum is the "desired" species in a transplanting project (Fonseca et al. 1987a); in the case of the Fowey site, it is the local dominant. However, it has low vegetative growth spread rate and therefore establishment rates (Fonseca et al. 1994), and may take years to provide any kind of sediment stability. May consider planting *Syringodium filiforme* first (Williams in Ecol Monogr.) thinks it a natural seccessional series, with *S. filiforme* enriching the sediments for T. testudinum. The impact on the donor bed of transplanting must be considered when choosing the species. Another reason for choosing *S. filiforme* is that donor beds of this species recover rapidly after the disturbance of removing transplants by excavation up to 0.25 m². This is true for beds that are protected from wave surge and current; smaller areas of excavation would be better in areas with greater water motion. T. testudinum beds recover more slowly following disturbance (Zieman 1976). Additionally, an experimental removal of T. testudinum resulted in initial dominance by *S. filiforme* (Williams 1990). However, *S. filiforme* does not provide the same level of sediment stabilization and accumulation.

Transplanting techniques have been investigated fairly thoroughly in the last 20 years, and seem to be well established for each species of seagrass (for reviews, see Phillips 1980, Fonseca et al. 1987b, 1988, 1994, and many others). At present, there are four main methods of transplanting seagrass, cores or sods, bare rhizomes, seedlings, and planting rhizomes or seedlings in peat pots. Success rates for each of these techniques vary among species and transplant site. To be successful, a transplant must survive an initial establishment period, and then expand areal coverage by producing more short shoots. Asexual reproduction, or generation of new shoots, is a key element in determining the success of transplant projects (Fonseca et al. 1987b). Short shoots form on new rhizomes that branch off of the parent, or transplanted, rhizome and shoot system. This is the major mechanism by which plantings spread out and increase areal coverage (Fonseca 1987b) as seedling recruitment is very spatially and temporally variable (Fonseca et al. 1985).

Transplanting techniques for seagrasses onto the Fowey site must be chosen to maximize early survivorship and minimize disturbance to the donor beds.

Transplanting of Syringodium filiforme has been relatively well studied. In a series of experiments using S. filiforme, Fonseca et al. (1994) compared three different planting methods (cores, stapled bare rhizome, and peat-pot plugs) for shoot addition rate and coverage. S. filiforme planted with cores produced an equal number of short shoots as those that were planted with staples, with peat pots producing significantly fewer shoots. In addition, there is evidence that the transplants that used the staple technique actually increase areal coverage faster than those planted with either of the other techniques (Fonseca et al. 1994). As cores were also considered more expensive per unit effort (time, effort, and materials) than staples, the authors concluded that using bare rhizomes anchored with staples was the recommended techniques for S. filiforme. Procuring planting material for this techniques is relatively

disturbing to the donor beds; however S. filiforme beds are relatively rapid to recolonize disturbed areas. It was noted that in areas where current or surge is an important factor, rhizomes and staples must be imbedded in the benthos while in low energy environments they can be placed on the surface.

There is also much information on techniques for transplanting Thalassia testudinum. T. testudinum has been easily transplanted by wild-collected seed for many years (Thorhaug 1974). In a study comparing transplant success for 3 sites in the Florida Keys (Fonseca et al. 1987b), survival after 4 months was high in a "low energy" environment (water movement across the benthos ranging from 1-6 $7.1\text{-}20\text{ cm} \cdot \text{s}^{-1}$), but no transplants survived in a "high energy" area ($7.1\text{-}20\text{ cm} \cdot \text{s}^{-1}$). This failure was attributed erosion, and it was suggested that the rhizomes were not buried to a sufficient depth. Survival was also low in an area where drifting macroalgae formed large mats on the benthos. Revegetation projects using this species have most often been limited by the slow rate of vegetative reproduction and therefore areal spreading (Fonseca et al. 1994). In a study of the spreading of transplants via asexual recruitment, data from both northern and southern Florida indicate that even after 600 days of growth, the average shoot density was much lower than that found in natural bed of T. testudinum (Fonseca et al. 1987b). These studies indicate that both seedling and bare rhizome transplants of T. testudinum can be successful in low energy areas where macroalgae is scarce. Seedling transplants have the advantage of being less disruptive to donor beds, but rely on a steady supply of wild-collected seeds, and a culturing facility.

FACTORS AFFECTING TRANSPLANT SUCCESS

Even given the correct choices of seagrass species and transplanting technique, there are several other important factors that affect the potential success of a transplanting project. Whenever you choose an area to plant seagrass, you have to ask "if this is a suitable environment, why aren't seagrasses already there?" (Fonseca et al. 1988). Most of the factors that can decrease survival and limit expansion of coverage are a function of site selection.

During the initial establishment time, transplants are especially vulnerable to disturbance of any kind. Early failure of many transplanting projects have been attributed to disturbances in the first few months, including inappropriate hydrodynamic regimes (erosion, burial), storms (physical removal of plantings), and bioturbation (Fonseca et al. 1994). The duration of this establishment period is species and site specific. For species like Syringodium filiforme, with relatively fast rates of vegetative reproduction, this period may be only 30 - 90 days, while for species like Thalassia testudinum with slower rates of expansion, this period may exceed a year.

Within a species the rate of both establishment and expansion is a function of environmental conditions. In mitigation work, one of the most common limiting environmental conditions that is a function of site selection is insufficient light penetrating the water column and reaching the benthos for an appropriate duration to support seagrass growth (Fonseca et al. 1988). Light penetration is a function of both water depth and water clarity. Too often sites are chosen that are too deep for the present water quality. Often planting sites are chosen based on the fact that the area supported seagrass beds in the past, but that is no guarantee that there was not a degradation of water quality in the interim. Although this is not likely to be a

consideration at the Fowey site, it is important to realize that just because a seagrass bed used to be there doesn't mean that the conditions are still suitable.

Another major contributor to transplant failure is insufficient knowledge of the hydrodynamic regime of the proposed site (Fonseca et al. 1989). Although the objective of many seagrass planting projects is to decrease erosion, seagrass beds only function to prevent erosion when they are relatively dense. Plantings may erode away or become buried before they can become established in areas with too much wave surge and current. Erosion control and sediment deposition only occurs once a planting has expanded areal coverage. Much of the loss of experimental transplants on the west coast of Florida was attributed to sediment movement (Fonseca et al. 1994, Mote Marine Laboratory and Mangrove Systems Inc. 1989), as well as other factors. In the case where a site is subjected to currents the plantings must be protected from bottom currents or surge in some way. This protection may have to last until the plants are able to form dense beds. The length of time to establish a mature seagrass bed is dependent on the physical/ chemical conditions at the site.

In many sites, it may be important to select an appropriate or optimal time of planting. In areas with highly variable temperatures, it is important to focus planting efforts on the beginning of the growing season. In other areas, one may want to target times when storms and resultant wave driven surges are less frequent. Fonseca et al. (1987b) suggests that, even in South Florida, the season of planting may be important, and suggests that spring may be the best time for planting. At the Fowey site this is true for two reasons. First, spring is the beginning of the growing season, and maximizes the amount of growth and expansion possible in the first year before the winter minimum growth. Second, this timing also maximizes the amount of time

and coverage expansion before the winter storms bring increased physical disturbance.

Addition of nutrients and protection from bioturbation or grazing may be important considerations when investigating the feasibility of seagrass transplanting for a specific site. There is much correlative and experimental evidence that suggests that nutrients limit seagrasses in natural beds (Short et al. 1985, 1990). Several experimentalists have investigated the usefulness of adding nutrients during a transplanting program in order to reduce nutrient limitation and accelerate establishment and growth with mixed results (Orth and Moore 1982, Kenworthy and Fonseca 1992, Fonseca et al. 1994). In a series of experiments in Tampa Bay, it appeared that rays caused a large amount of mortality of seagrass transplants (Fonseca et al. 1994). Pinfish grazing and ray and crab burrowing affected Syringodium filiforme transplants in 2 sites in the Florida panhandle and 4 sites in the Florida Keys (Fonseca et al. 1987b). From these studies, one can see that it is critical to evaluate availability of nutrients as well as the frequency and scale of bioturbation and grazing in the Fowey site prior to transplanting.

PROBLEMS SPECIFIC TO THE FOWEY SITE

This sector of the MS needs to be added after the meeting. It needs to synthesize what the physical oceanographer/sedimentologist - types have to say about this site.

- A. Deeper grass bed, solight may be a problem, and the growth rate to a density to become "established" and to be able to stabilize sediment and not be "blown out" may be very long (run simulation model to test?)

B. Near are of shifting sands. Thalassia testudinum stabilizes sediment, but needs to be on a stable area to establish. can take a certain amount of burial after establishment (post hurricane data as well as obs. at Elkhorn). To take advantage of the fastest growth rate, need to plant in spring, but then if there is a hurricane or tropical storm, its shot... so its a gamble.

C. Very important to characterize the site (light, temperature, currents, surge, sediment movement) over a long enough time to determine if conditions are suitable for establishment.

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Table 1. Synopsis of the sequence of events at the Fowey shipwreck site.

1975	BNP surveyed and 18 shipwrecks found. At his time the Fowey was not found they, but it was noted there was a wreck reported at the Anchorage
1980	In June-July the wreck was located and visible features were surveyed. It was noted there was evidence of salvors and "excavation" at the site.
1980	In September, archeologists surveyed again. This reported noted that there was evidence that treasure salvors removed protective vegetation and started a process of accelerating erosion and exposure. •• Ask Richard if they actually SAW where cover had been removed, or assumed it was there prior to disturbance!
1983	In May-June, archeologists did an airlift excavation of several areas. This report stated that the salvor had caused damage by prop-wash. ••• Is this new damage between 1980-83?? In an effort to stabilize the area after excavation, they planted seagrass (see summary below)
1992	In August, Hurricane Andrew exposed large portions of the Fowey that were previously buried.; these portions were mapped in September 1992
1993	Between Sept 1992 and July 1993, there was archaeological surveys of the newly exposed areas of the wreck. In July, the site was recovered by 10-15 cm of sediment.
1994	Tropical storm Gordon deposited more sand onto the Fowey site area

Table 2. Reported values for productivity of three species of seagrass

Species	Location	Value	Source
<i>Thalassia</i>	Virgin Islands -disturbed area	33-97 mg dw · m ⁻² · day ⁻¹	Williams 1988
	Virgin Islands -pristine	700-27,000 mg dw · m ⁻² · day ⁻¹	
	Tague Bay	1000 - 6000 mg dw · m ⁻² · day ⁻¹	
<i>Thalassia</i>	Florida Bay	mean = 70 mg dw · m ⁻² · day ⁻¹	Zieman et al. 198
<i>Thalassia</i>	Florida Bay	+ nutrients 3,340 mg dw · m ⁻² · day ⁻¹ - nutrients 2,150 mg dw · m ⁻² · day ⁻¹	Powell et al. 1989
<i>Thalassia</i>	Keys and Caribbean	300-1,400 mg dw · m ⁻² · day ⁻¹	Tomasko and Lapointe 199
<i>Thalassia</i>	Tampa Area	20-31 mg dw · g dw ⁻¹ · day ⁻¹ =(2-3%/day)	Dawes and Tomasko 1988
<i>Thalassia</i>	Tampa Area	min fall 0.5 mg dw · g dw ⁻¹ · day ⁻¹ max spr-sum 27 mg dw · g dw ⁻¹ · day ⁻¹ =(2.7%/day)	Tomasko and Dawes 1990
<i>Halodule</i>	Florida Bay	+ nutrients 16,360 mg dw · m ⁻² · day ⁻¹ - nutrients 13 mg dw · m ⁻² · day ⁻¹	Powell et al. 1989

Table 2 (Continued)

Species	Location	Value	Source
<i>Halodule</i>	Texas estuary	-max sum 5-8 mm·day ⁻¹ -min winter 0-3 mm·day ⁻¹	Dunton 1990
<i>Halodule</i>	Texas estuary	May 580 mg dw·m ⁻² ·day ⁻¹ Sept 2,120 mg dw·m ⁻² ·day ⁻¹ (+ org nut 200ug leaf tissue dw·day ⁻¹)	Pulich 1989
<i>Syringodium</i>	Bahamas	0.62 mg dw·shoot ⁻¹ ·day ⁻¹ 0.5-1.4 cm·shoot ⁻¹ ·day ⁻¹ where ave #shoots·m ⁻² =10,200 therefore ~ 6,300 mg dw·m ⁻² ·day ⁻¹	Short et al 1985
<i>Syringodium</i>	Bermuda	0.23 cm·leaf ⁻¹ ·day ⁻¹	Bermuda Biol Statio

Table 3. Values reported for maximum biomass of three species of seagrass

Species	Location	Value	Source
<i>Thalassia</i>	Virgin Islands	80-200 shoots·m ⁻²	Williams 1988
	-disturbed area	1.3-4.6 g dw·m ⁻²	
	Virgin Islands -pristine	15-81 g dw·m ⁻²	
<i>Thalassia</i>	FL Keys and Caribbean	27-70 g dw·m ⁻²	Tomasko and Lapointe 1991
<i>Thalassia</i>	Florida Bay	mean = 142 g dw·m ⁻² range = 25.2-470.4	Fourqurean and Zieman 199
<i>Thalassia</i>	Florida Bay	SW: 60-125 g dw·m ⁻²	Zieman et al. 1989
		NE: 0-30 g dw·m ⁻²	
<i>Thalassia</i>	Florida Bay	control = 25 -65 g dw·m ⁻²	Powell et al. 1989
		enrich = 115-170*	
<i>Thalassia</i>	West C of FL near Tampa	x=385 g dw·m ⁻²	Dawes et al. 1985
		max-spring 838 g dw·m ⁻²	
<i>Thalassia</i>	Near Tampa	300-1100 shoots·m ⁻²	Dawes and Tomasko 1988
		40-160 g dw·m ⁻²	
<i>Thalassia</i>	Near Tampa	min summer 144 shoots·m ⁻²	Tomasko and Dawes 1990
		max fall 592 shoots·m ⁻²	

3
Table 2. (Continued)

Species	Location	Value	Source
<i>Halodule</i>	Florida Bay	control = 0 to occasional enrich = 40 - 150 g dw·m ⁻²	Powell et al 1989
<i>Halodule</i>	Texas estuary	7- 70 g dw·m ⁻² 3500 - 10,000 shoots·m ⁻² Min in winter, max in summer	Dunton 1990
<i>Syringodium</i>	Bahamas	139-190 g dw·m ⁻² 7,900 - 12,500 shoot·m ⁻²	Short et al. 1985

*enrichment effect on biomass was temporary in Year 1; by Year 3, went down and switched to *Halodul*