Restoration Ecology
THE JOURNAL OF THE SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL

RESEARCH ARTICLE

Survival and Expansion of Mechanically Transplanted Seagrass Sods

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Abstract

Although planting seagrass is not technically complex, the ability to plant large areas is limited by the time-consuming nature of manual methods. Additionally, manual methods use small, spatially isolated planting units (PUs; shoot bundles or plugs/cores) that are often highly susceptible to disturbance. The likelihood for harvesting intact apical meristems may be higher with large sods compared to smaller units, thus increasing survival and expansion rates. Here, we examined the survival and expansion of large units (1.5 × 1.2 m) of seagrass transplanted using a mechanized planting boat (Giga Unit Transplant System; GUTS). Twenty-seven units of seagrass (18 *Halodule wrightii* and 9 *Thalassia testudinum*) were transplanted and monitored for survival, shoot density, and expansion. After 3 years, 74.1% of the units had survived (66.7% *H. wrightii* and 88.9% *T. testudinum*) with 12 *H. wrightii* units having expanded substantially beyond the bounds of the original PU, merging with adjacent units to form spatially continuous patches of seagrass. High survival rates for *T. testudinum* should be interpreted in light of concomitant declines in density and lack of significant expansion after 3 years. In its tested configuration, the GUTS was a viable method for transplanting *H. wrightii* where donor and receiver sites were in close proximity (<2 km; a current limitation of the GUTS design used here). However, based on the reduced density and lack of significant expansion of *T. testudinum* that has persisted 3 years post-transplant, the GUTS cannot yet be fully recommended for transplanting this species.

Key words: ***Halodule wrightii*, mechanized planting, restoration, Shoal grass, *Thalassia testudinum*, transplanting, Turtle grass.**

Introduction

Seagrass planting techniques have proven to be an effective means of creating viable seagrass habitat (Homziak et al. 1982; McLaughlin et al. 1983; Thayer et al. 1986; Fonseca et al. 1996*b*) and restoring ecosystem function (Fonseca et al. 1996*a*; Sheridan 1999; Short et al. 2000). Techniques are varied, involving seed sowing (Orth et al. 1994; Harwell & Orth 1999), seedling/single shoot planting (Thorhaug 1974; Fonseca et al. 1985; Balestri et al. 1998), shoot bundles (Derrenbacker & Lewis 1982; Fonseca et al. 1982), peat pots and plugs (Robilliard & Porter 1976; Fonseca et al. 1994), and wire frames (Short et al. 1999, 2002). Although planting seagrass is not technically complex, the ability to plant large areas remains constrained by the costly, time-consuming nature of manual methods and the cost of post-planting monitoring and oversight (Fonseca et al. 1998*b*). In the United States, recent attempts to increase the efficiency of seagrass restoration efforts via a mechanized method using isolated seagrass bundles did not offer significant improvement over manual methods, primarily due to the failure of the transplant machine to adequately establish transplant units in the sediment (McEachron et al. 2001; Fishman et al. 2004).

The aforementioned transplanting methods use small, spatially isolated planting units (PUs) that are often highly susceptible to erosion and bioturbation because of their limited anchoring capabilities (Fonseca et al. 1998*b*). Using transplant units that are larger in size, whereby a portion of the rhizosphere is maintained and planted along with the shoots, may improve anchoring and thus reduce susceptibility to erosion. Limited success with manual transplants in high–wave exposure environments in Western Australia (Kirkman 1998; Paling et al. 2000) led to the development of ECOSUB, a machine for harvesting and planting large sods (0.25 m^2 area and 0.5 m deep) of seagrass. This method has been deemed successful largely due to the increased survival of the sods over manually transplanted bundles (Paling et al. 2001*a*, 2001*b*).

In April 2003, scheduled dredging of residential canals on Longboat Key, located on Sarasota Bay, Florida, U.S.A. (lat 27°23′49″N, long 82°38′41″W), afforded the opportunity to salvage seagrasses that had colonized the canals since the previous maintenance dredging for use in an experimental transplant study using a recently developed mechanized method that extracts and plants blocks of seagrass (Giga Unit Transplant System [GUTS]; U.S.

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doi: 10.1111/j.1526-100X.2008.00376.x

Patent No. 6,684,536). Previous attempts to transplant seagrass using the GUTS have been limited to mitigation and have not followed rigorous scientific method. In this study, we examine the survival and expansion of seagrass (*Halodule wrightii* and *Thalassia testudinum*) units planted using the GUTS. To our knowledge, this is the first attempt to evaluate a fully mechanized seagrass/sediment planting procedure in the United States.

Methods

Transplanting Machine

The mechanized GUTS, owned and operated by Seagrass Recovery, Inc., Ruskin, Florida, U.S.A., comprised a hydraulically operated grab bucket mounted on a modified pontoon boat (7.3 m length; Fig. 1) and capable of harvesting a single 1.5-m-long × 1.2-m-wide × 0.3-m-deep sod of seagrass. The bucket comprised a set of primary (Fig. 2, #22 & 24) and secondary (Fig. 2, #14 & 16) jaws. During harvesting, the leading edges of the primary jaws penetrate the substrate and encompass a seagrass sod, whereas the secondary jaws (counterweighted) remain passive. The seagrass is held within the bucket that remains suspended above the water's surface during transport to the transplant site. Each half of the primary jaws is equipped with a wiper blade type apparatus (Fig. 2, #47 & 48), which assists in the deployment of the transplant unit. During transplanting, the secondary set of jaws pierces the sediment (Fig. 2B) as the bucket lowers, creating a receiving depression as the bucket opens (Fig. 2C), thus facilitating sod deposition near the sediment surface level. To reduce seagrass desiccation during transport, the GUTS is fitted with a seawater pump and hose that can be used to keep the transplant unit moist. A two-person crew is required to drive, harvest, and deploy transplant units.

Figure 1. The Giga Unit Transplant System (GUTS). (Photo by M. O. Hall.)

During test runs of the GUTS, a number of operational limitations were discovered that constrained its use and that must be considered when choosing seagrass donor and receiver sites. The machine was restricted to water depths in the range of 0.6–1.5 m. In deeper water (>1.5 m), the primary jaws cannot obtain a full extraction. Although the grab bucket was able to obtain donor plants during test runs at this deeper depth limit, the amount of sediment extracted was not sufficient to yield a PU that would remain intact during transit and deposition. When the planting (receiver) site depth approached this deeper limit, the secondary jaws were not able to create a sufficiently deep depression and so the PUs were deposited very shallow, oftentimes resting on top of the substrate where they were highly vulnerable to tidal current-induced erosion or acceleration reaction and lift forces under waves.

The sailing platform of the GUTS itself (modified pontoon boat) also limits its usage to fairly calm seas and unconsolidated sediments. The maximum operational speed of the GUTS (approximately 13 km/hr with sod in place and approximately 18.5 km/hr empty) and its ability to remove and transport only one sod at a time limit the rate at which sods may be transplanted. During test runs, the GUTS required, on average, 40 minutes round-trip for a distance of nearly 2 km between donor and receiver sites. At this rate, barring especially complicated navigation, it was estimated that approximately 12 sods could be transplanted in one 8-hour workday.

Donor Site Selection (Salvage Operation)

The seagrasses Turtle grass (*Thalassia testudinum*) and Shoal grass (*Halodule wrightii*) were salvaged from selected residential canals located in Sarasota Bay prior to a maintenance dredging project by the Town of Longboat Key. Dredging of any kind in Florida is an activity requiring both federal and state oversight and, when seagrasses are involved, may require mitigation for seagrass loss. However, the donor canals used in this study were exempt from mitigation for dredging due to grandfather provisions within the State of Florida Statutes.

Each canal was visited prior to dredging activities and visually assessed by snorkeling to determine acceptability as a donor site. Acceptable canals included those falling within the operational depth limits of the GUTS and exhibiting a minimum of 50% cover (determined using the Braun-Blanquet technique; Fourqurean et al. 2001) of either of the target seagrass species. The 50% cover limit was somewhat arbitrary but based on visual inspection, was thought to include sufficient seagrass to facilitate sod integrity during transit and subsequent deposition.

Planting Site Selection

Because this was an experimental planting, we did not adhere to standard site selection protocol used for mitigation or restoration projects (Fonseca et al. 1998*b*). Rather,

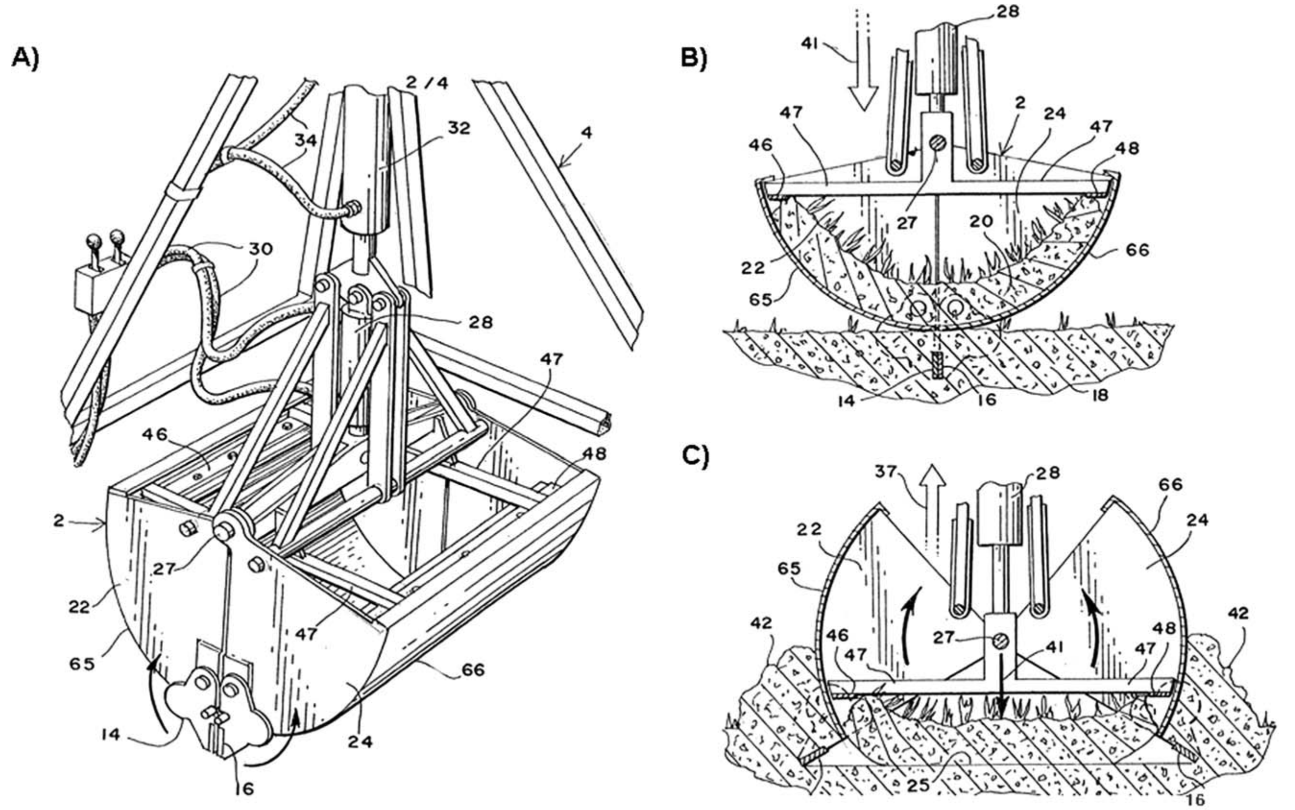

Figure 2. Schematic diagrams of the GUTS bucket grab. (A) The closed position indicating primary jaws (#22, 24), secondary jaws (#14, 16), and wiper blade apparatus (#47); (B) engaged with the substrate; and (C) creating a furrow and depositing a seagrass PU.

we targeted landscapes where existing seagrass was continuous yet interspersed with areas of bare substrate, suggesting that the unvegetated areas were within acceptable environmental limits to support seagrass growth but were currently vacant only due to the temporal dynamics of seagrass cover. These unvegetated gaps also needed to be large enough to install a number of PUs and fall within the operational depth and distance limits of the GUTS. To determine any difference among the planting sites in terms of hydrodynamic regime, replicate flowmeters (Tsurumi-Seiki Co., Ltd., Yokohama, Japan) were established at each site and readings recorded every hour during a 12-hour period to determine tidal current speeds (peak free-stream speed at the lunar maxima). In addition, relative exposure to waves was calculated for each site throughout the duration of the study period using an index computed by the wave exposure model developed at National Oceanic and Atmospheric Administration's Center for Coastal Fisheries and Habitat Research (Fonseca et al. 2002).

Experimental Design

In April 2003, the GUTS, operated by personnel from Seagrass Recovery, Inc., was used to harvest and plant a total of 27 seagrass sod PUs, 9 *T. testudinum* and 18 *H. wrightii*. The GUTS was directed to selected donor and receiver sites by scientific staff while recording the time and distance required for travel between the two locations. Critical steps of the transplanting process were documented with digital video. PUs were installed at three sites 2–12 km distant from one another and not more than 2 km distant from a donor site (site 1 = 1 *T. testudinum* and 4 *H. wrightii*, site 2 = 0 *T. testudinum* and 9 *H. wrightii*, and site 3 = 8 *T. testudinum* and 5 *H. wrightii*). Allocation of sods among sites was based on logistical constraints. The number of PUs planted at a given site was dependent upon the amount of available unvegetated substrate. Likewise, the number of PUs planted within a specific bare patch varied with the size of the patch. The average distance between adjacent PUs was 8 m with 2 m between any given PU and the surrounding natural seagrass bed.

PU perimeters were mapped by walking the perimeter of the unit using a surveyor grade Differential Global Positioning System (Trimble GPS Pathfinder Pro XR receiver and Trimble TSC1 data collector) at less than 0.5 m resolution. A metal stake was inserted into the center of each PU as a reference point, and the location of the stake was recorded with the DGPS. Additionally, a weighted buoy was established outside the PU to mark its location. Immediately following transplanting, three replicate quadrats (0.125 × 0.125 m) were haphazardly tossed into each PU, and all seagrass short shoots (sensu Tomlinson & Vargo 1966) within the quadrats were counted to determine short-shoot densities. Digital video of each PU was recorded.

PUs were monitored 6, 12, 18, 24, and 36 months post-transplantation. For each PU, measures of survival (presence/absence of shoots), short-shoot density, perimeter expansion, and species composition were made employing the aforementioned techniques. Current seagrass monitoring protocols define PU survival as the presence of at least one short shoot (Fonseca et al. 1998*b*). We adopted this method, although our PUs never contracted to such a degree. When PUs had contracted to a size small enough to preclude the use of DGPS mapping ($\leq$10 shoots), a 1.5 × 1.5–m grid (subdivided into 10 × 10–cm squares) was centered over the metal stake. Presence/absence of seagrass shoots within each square was recorded. Area was calculated by summing the total number of squares containing seagrass and multiplying that number by 0.01 to yield area in square meters.

Statistical Analyses

Only data for those PUs surviving to 36 months were analyzed. Due to inherent differences in growth patterns between species, each was analyzed separately. The small and unequal sample sizes among sites prevented an accurate statistical assessment of this factor for *H. wrightii*. In addition, the observed low current speeds and exposure values were well below what may be expected to contribute to seagrass bed pattern (Fonseca et al. 1985; Fonseca & Bell 1998). Thus, site differences, as defined by hydrodynamic regime, were removed from the analyses but are reported anecdotally. All statistical analyses were performed using SAS Version 9.1 (SAS Institute, Inc. 2004).

Halodule Wrightii

A situation arose where two *H. wrightii* PUs had coalesced and were impossible to differentiate after 24 months. For the purposes of calculating PU survival, the two were assumed to have both survived to 36 months. However, for statistical analyses, the individual areas of the two units were added together for 0, 6, 12, and 18 months and the two units were treated as one with a reduction in sample size by 1. Similarly, the original short-shoot densities for each were averaged together and treated as one unit.

Repeated measures analysis of variance (PROC MIXED; autoregressive of order 1 covariance structure) was used to compare differences in (square root + 0.5) transformed short-shoot densities at each monitoring time. Post hoc comparisons (PROC GLM; Ipe 1987) were performed using the Bonferroni adjustment for multiple comparisons.

Unlike shoot density, we anticipated a priori that the measured levels of PU area would increase as monitoring time increased. Planting area would logically increase over time if the plants were growing. In contrast, we had no expectation that shoot density would increase, decrease, or stay constant even if plants were growing. A nonparametric test was used due to the nonnormality of the dataset and violation of the assumption of homogeneous variance. Page's (1963) nonparametric trend test (Conover 1999) followed by post hoc comparisons (PROC GLM; Ipe 1987) using the Bonferroni adjustment for multiple comparisons were used to compare differences in PU area among monitoring times.

Thalassia Testudinum

Because transformation did not correct for nonnormality and homogeneity of variance, we applied the nonparametric Friedman test (Conover 1999) followed by post hoc comparisons (PROC GLM; Ipe 1987) using the Bonferroni adjustment for multiple comparisons to compare differences in short-shoot density among monitoring times.

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Results

Mean peak tidal current speeds at sites 1 and 3 were 8.55 and 10.34 cm/second, respectively, and 2.34 cm/second for site 2. Relative wave exposure at site 2 (1,727) was 5 times higher than site 1 (319) and 1.7 times higher than site 3 (961); site 3 was 3 times more exposed than site 1.

It has been suggested that where tidal current speeds are less than 15 cm/second, wave exposure alone should be considered when predicting seagrass coverage (Fonseca et al. 1998*b*). High–wave exposure values in Tampa Bay range from 20,000 to 30,000 with hurricane conditions pushing the index as high as 120,000 (Fonseca, unpublished data); thus, the wave exposure environment for this experiment (approximately 1,700 maximum) was at the extreme low end of the local range.

Halodule Wrightii

Three years post-transplantation, 12 of 18 *Halodule wrightii* PUs had survived (66.7%). Though it was not possible to test this statistically (see Methods), there appeared to be site-specific differences in survival. At the two northern sites (sites 1 and 3), survival of *H. wrightii* sods after 36 months was 50 and 40%, respectively. The southern site 2, which had the highest wave exposure, had 88.9% survival. Interestingly, site 2 also boasted the highest PU areas but appeared to have the lowest shoot densities (Fig. 3). Site 1 exhibited the lowest PU areas (Fig. 3).

There was a significant effect of monitoring time ($p < 0.001$) on shoot densities (Table 1). Mean shoot density declined 6 months post-transplant and remained depressed through 12 months but was able to rebound significantly after 18 months, a trend that continued through 36 months (Fig. 4A).

Page's trend test was significant ($p < 0.001$) indicating that PU areas increased with increasing monitoring time. Multiple comparison tests revealed that noticeable expansion of PU areas began by the first monitoring time. Significant expansion beyond the initial PU size was not detected until 18 months, with an additional significant increase in PU areas at 24 months and continuing at 36 months (Fig. 4A). Growth and expansion of *H. wrightii* PUs after 36 months resulted in a net gain of 3,512.4 m^2 of seagrass (Fig. 5A). In one instance, a single sod had expanded to nearly 400 times its original size. The absence of *H. wrightii* in control shoot counts made at each site prior to transplanting confirms that these expanded patches truly originated from our PUs.

Thalassia Testudinum

Eight of nine (88.9%) *Thalassia testudinum* PUs had survived after 3 years. Monitoring time had a significant effect on shoot density ($p < 0.01$; Table 1). After initial planting, shoot densities exhibited a steady decline during the first year, showed signs of rebound at 18 months, but then subsequently fell and remained significantly lower at 24 and 36 months than at the time of initial planting (Fig. 4B). Page's trend test was not significant ($p > 0.05$), demonstrating that there was no evidence for a progressive increase in *T. testudinum* PU areas over time. Rather, PU areas exhibited a significant steady decline during the first-year post-transplant (Fig. 4B). At 18 months, PU areas began to rebound with continued significant increases in area at 24 and 36 months, though not exceeding the initial PU size (Fig. 4B). Growth and expansion of five PUs over 36 months resulted in a net gain of 11.8 m^2 of *T. testudinum* (Fig. 5B). The three remaining PUs decreased in size.

Discussion

After 36 months post-transplantation, growth and expansion of 20 surviving mechanically planted seagrass sods, representing 38.4 m^2 of seagrass planted, resulted in a net gain of over 3,500 m^2 of seagrass habitat, mostly from *Halodule wrightii* patch expansion. In addition, PUs exhibited high survivorship over time, exceeding the mean reported from 53 published studies using manual transplants (42% reported in Fonseca et al. 1998*b*). Survivorship appeared to be species specific, with higher survival of *Thalassia testudinum* PUs. However, these higher rates should be approached with caution considering that on occasion, fewer than 10 short shoots were observed for a number of *T. testudinum* PUs. The decline in shoot density and lack of significant areal expansion after 3 years post-transplant for *T. testudinum* PUs emphasize the slow vegetative growth rate and lag between colonization and spreading for this species and mirror results for other, notoriously slow-spreading species transplanted as sods (Paling et al. 2001*a*, 2001*b*). Although PU survival rates for *H. wrightii* were lower than those for *T. testudinum*, the tremendous expansion of the PUs indicates the pioneering nature of this species and its capacity to rapidly colonize an area. Although *T. testudinum* may be the ultimate target species of a given restoration, the suggestions of previous studies that called for initially planting a faster growing species like *H. wrightii* to promote initial planting stability appear to still hold using sod techniques. Use of such pioneering species stabilizes sediments rapidly and contributes to the establishment of a functional seagrass habitat ("compressed succession"; Derrenbacker & Lewis 1982; Fonseca et al. 1987). Given the apparent, prolonged lag time between planting and patch expansion for *T. testudinum*, we suggest that future work with sods of this species should consider including the establishment of *H. wrightii* plantings by traditional, manual methods around the perimeter to examine the potential for facilitating *T. testudinum* spreading and improving patch integrity.

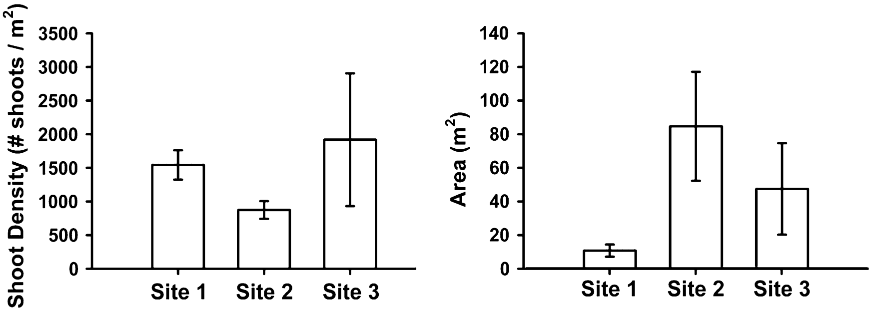

Figure 3. Mean (±SE) shoot density and PU area of transplanted *Halodule wrightii* at different receiver sites.

Table 1. Results of repeated measures analysis of variance (ANOVA) (*Halodule wrightii*) and the Friedman test (*Thalassia testudinum*) for the effect of monitoring time on PU short-shoot density.

ANOVA	*Effect*	*Numerator df*	*Denominator df*	*F*	*p*
H. wrightii					
Density	Monitoring time	5	50	8.30	<0.0001**
Friedman	*Source*	*df*	*MS*	*F*	*p*
T. testudinum					
Density	Monitoring time	5	10.5125	4.33	0.0036*

* $p < 0.01$; ** $p < 0.0001$.

Although *H. wrightii* short-shoot densities initially declined, the high growth rate and opportunistic nature of this species allowed it to rebound to original transplant densities within 18 months, remaining stable thereafter until a surge of growth occurred between 24 and 36 months. Significant expansion of surviving *H. wrightii* PUs was apparent at 18 months and continued through 36 months, at which point PUs had begun to coalesce with surrounding natural populations and neighboring PUs, corroborating the 3-year minimum monitoring recommended by Fonseca et al. (1998*b*) for this species. The rapid expansion observed for *H. wrightii* PUs in this study resembles findings describing seagrass patch growth as self-accelerating (Kendrick et al. 2005; Sintes et al. 2005 and references therein) because patch expansion rates increase with increasing patch size and age. Self-accelerating patch growth has been reported for seagrasses from the Mediterranean and Western Australia (Vidondo et al. 1997; Kendrick et al. 1999).

In contrast with *H. wrightii*, *T. testudinum* PUs were just beginning to show signs of persistence and expansion at 36 months, although not yet substantially different from that at the time of initial planting. These results are not surprising, given the slow growth rate of this climax species. Shoot generation rates and coverage rates for transplanted *H. wrightii* have been shown to be considerably higher than those for *T. testudinum* (Fonseca et al. 1987). Continued monitoring of *T. testudinum* PUs, up to at least a minimum of 5 years, will be necessary to determine the point at which PUs have successfully established (Fonseca et al. 1998*b*).

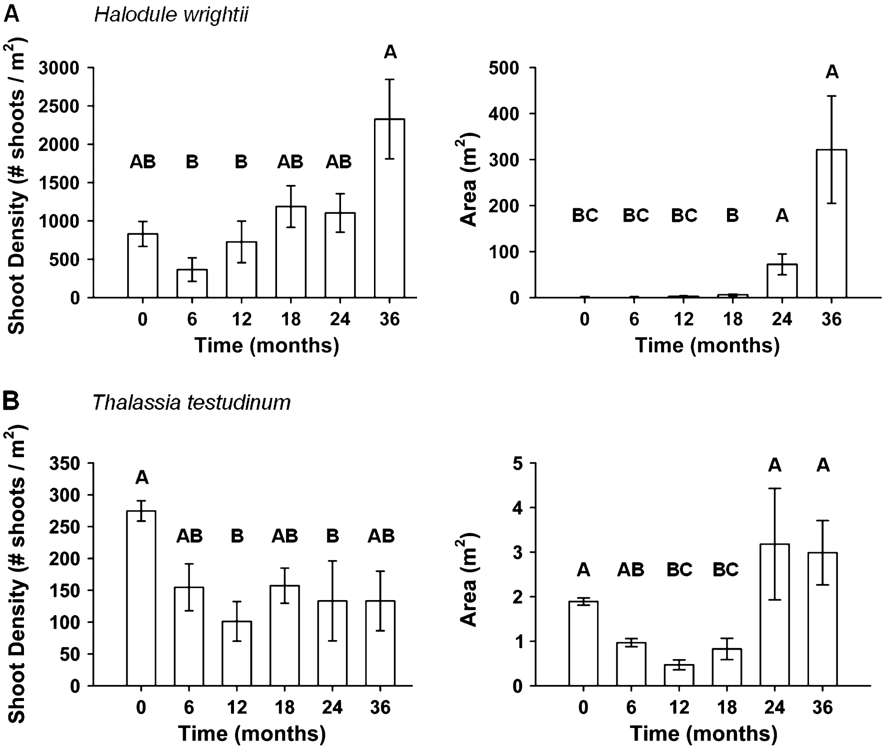

Figure 4. Results of post hoc comparisons among monitoring times using the Bonferroni adjustment for multiple comparisons for mean (±SE) shoot density and area of transplanted (A) *Halodule wrightii* and (B) *Thalassia testudinum*. Means with the same letter are not significantly different at the $\alpha = 0.05$ level.

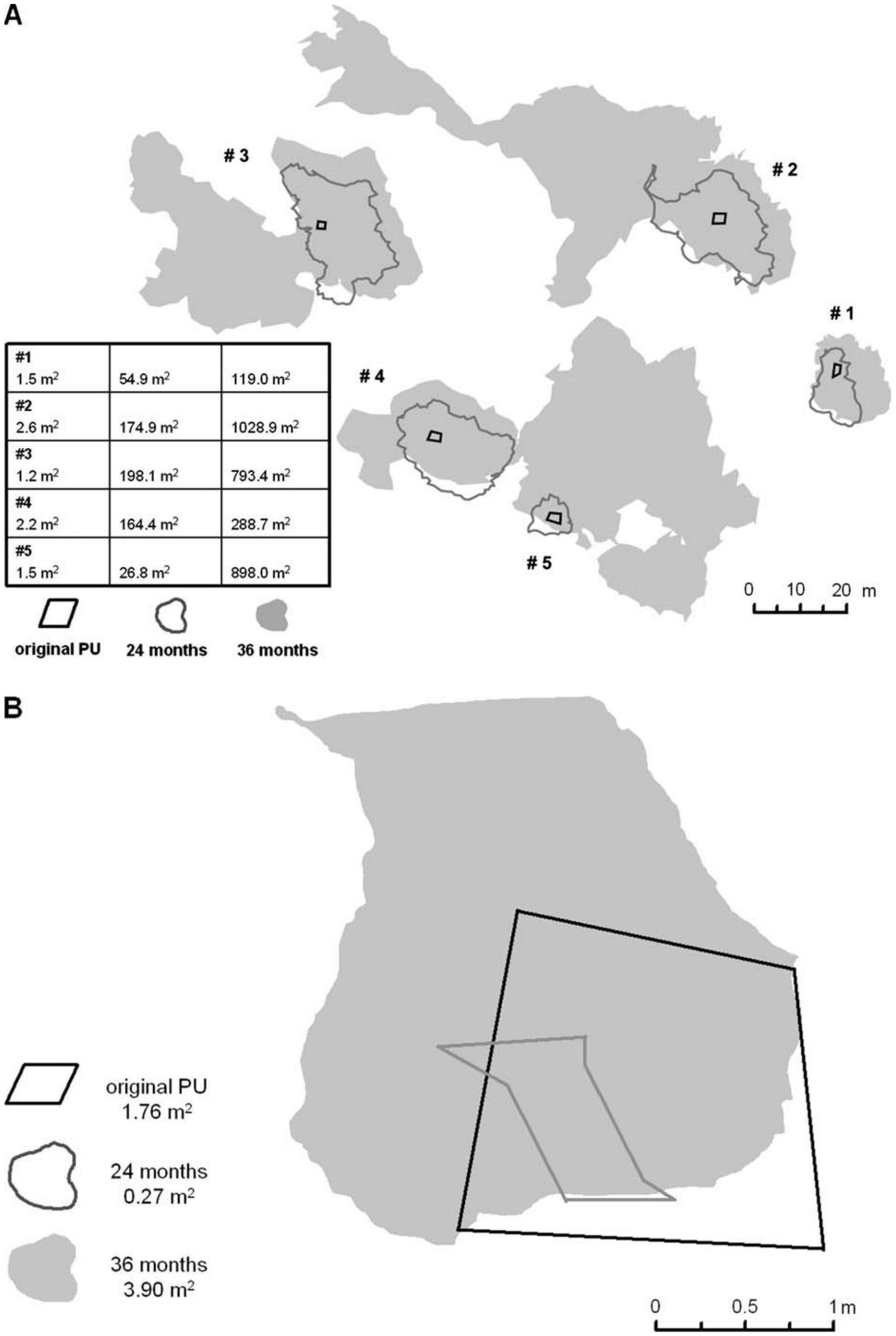

Figure 5. GPS-mapped growth and expansion of (A) five *Halodule wrightii* PUs (#1–5, site 2) and (B) one *Thalassia testudinum* PU (#9, site 3).

Five additional projects (unpublished data) have used GUTS technology (Table 2). Only one of these monitored individual PUs for survival in combination with PU areal coverage and PU shoot densities; three standard metrics of plant performance were used to determine the success of a transplant effort (Fonseca et al. 1998*b*). One project monitored PU survival and expansion but not shoot densities. Two projects monitored coverage and shoot densities; however, these were collected across the entire transplant area and not PU specific. The final project monitored individual PU survival alone. The inability to directly compare these six projects due to inconsistent monitoring methods emphasizes the importance of the adoption of standard success criteria for seagrass transplanting projects.

It is important to note that the Port Manatee and Durante Park projects (Table 2) both used a prototype version of the GUTS used in the current study that was faster and was mounted with three buckets in sequence. Although a large number of PUs were able to be transplanted over a 7-month period, at Port Manatee, only

Table 2. Comparison of six transplant studies using GUTS technology.

Site (Monitoring Period)	*Species*	*No. of Units Transplanted and Monitored*	*Area Transplanted (m^2)*	*No. of Units Surviving (% of Transplanted)*	*Areal Expansion (m^2) (% of Transplanted)*	*Study-Specific Success Criteria*
Longboat Key, FL (current study; 3 years)	*Thalassia testudinum* *Halodule wrightii*	9 18	16.2 32.4	8 (88.9) 12 (66.7)	11.8 (72.8) 3,512.4 (10,492)	Survival, areal expansion, and shoot density per PU
Tampa Bayside Marina, Tampa, FL[a] (monitoring period unknown)	*H. wrightii*	102	183.6	Units not monitored individually	No data	Shoot density and cover at fixed locations within entire planted area
Lassing Park, St. Petersburg, FL[b] (2 years)	*H. wrightii*	70	126	Units not monitored individually	647.4 (513.8)	Areal expansion and shoot density over entire planted area
Isle of Wight, Ocean City, MD[c] (2 years)	*Zostera marina*	30	54	30 (100)	29.7 (55.0)	Survival, areal expansion, and shoot density per PU
Durante Park, Longboat Key, FL[d,e] (2 years)	*H. wrightii*	10	18	4 (40.0)	76 (422.2)	PU survival and total areal expansion
Port Manatee, Tampa, FL[d,f] (9 months)	*T. testudinum*, *H. wrightii*	11,609	20,896	~100 (<1)	No data	Individual PU survival

[a] Scheda Ecological Associates, Inc. (2005).
[b] J. Anderson, Seagrass Recovery, Inc., Ruskin, Florida (unpublished data).
[c] BayLand Consultants & Designers, Inc. (2005).
[d] Employed the prototype GUTS equipped with a diamond-shaped bucket. See text for details.
[e] R. Poyner, Florida Department of Environmental Protection, Tampa, Florida (unpublished data).
[f] Lewis et al. (2006).

approximately 1% of the PUs survived after 9 months (Table 2). The bucket designed for this prototype had a diamond shape, with steeply sloping sides. In addition, the wiper blade apparatus, which facilitates PU removal from the bucket when the jaws open, was not in place at the time. Combined, these factors often led to shallow deposition of PUs and situations where the PU simply fell out of the bucket when it was opened, often with the grass side down (Lewis et al. 2006). This left the units susceptible to erosion, an important factor given the unstable hydrodynamic environment of the planted area (Lewis et al. 2006), further highlighting the consequences of site selection in seagrass transplanting projects. The Durante Park units fared better, likely a result of the protected nature of the transplant area. The bucket design issues were brought to light during the Port Manatee effort that led to a redesign of the GUTS into its current configuration. Although the GUTS shows promise for opportunistic seagrass species (Table 2), there have not yet been sufficient studies to fully examine the efficacy of the method for slow-spreading species, an issue consistent with the ECOSUB findings (Fonseca et al. 1998*a*; Paling et al. 2001*a*). It is difficult to compare these two mechanized methods (ECOSUB and GUTS) directly because conditions in Western Australia are more severe and seagrass habitats are deeper (approximately 10 m). Nonetheless, results are analogous. Survival of ECOSUB sods was 70% overall after 3 years with species-specific trends (Paling et al. 2001*a*, 2001*b*). Due to the nature of the GUTS design, survival of PUs under high-energy regimes was not meaningfully addressed here and warrants further investigation.

Therefore, we conclude that in a salvage operation and in the design tested here, the GUTS technique can successfully transplant relatively large units of *H. wrightii* where donor and receiver sites are in close proximity (<2 km apart). However, a cost comparison for *H. wrightii*, a species that has been shown to be readily transplanted with traditional, low-technology approaches, has not been done. Moreover, based on the reduced density and lack of significant expansion of *T. testudinum* 3 years post-transplantation and the slow-growing nature of the species, the GUTS does not overcome the limitations historically associated with transplanting small clonal units of *T. testudinum*. Other considerations to accelerate *T. testudinum* spreading, such as mixed-species plantings as suggested above, may enhance the overall performance of the machine for *T. testudinum*, but this too remains to be tested.

Implications for Practice

- The mechanical planting method successfully transplanted sods of the seagrass *Halodule wrightii* where donor and receiver sites were in close proximity (<2 km apart) and between 0.6 and 1.5 m water depth.

- In its tested configuration, this method is recommended for transplanting *H. wrightii* solely for salvage operations.
- Currently, this mechanical method is not recommended for transplanting *Thalassia testudinum* based on reduced densities and lack of significant expansion of sods 3 years post-transplant.
- Due to the slow-growing nature of *T. testudinum*, longer-term monitoring of this species is suggested (5 years).
- Although not tested here, mixed-species planting (i.e., *H. wrightii* planted in combination with *T. testudinum*) may promote an environment more favorable for *T. testudinum* expansion.

Acknowledgments

We appreciate the assistance of J. Anderson, B. Williams, and the staff of Seagrass Recovery, Inc., for providing and operating the GUTS. We recognize D. Berns, J. Bowles, K. Ferenc, F. Hall, J. Hyniova, J. Kunzelman, B. Robbins, and S. Slade for field assistance. Special thanks to B. Heckert, R. Lewis, R. Poynor, T. Reis, and B. Upcavage for graciously providing data for Table 2 and to Seagrass Technologies, LLC for allowing the use of their schematic diagrams of the GUTS bucket. We are especially grateful for the statistical guidance provided by W. J. Conover. We also acknowledge A. Malhotra for calculating wave exposures. The manuscript was improved by comments from S. Bell, E. Griffith, K. Hammerstrom, D. Johnson, J. Kenworthy, K. Kiehl, P. Marraro, V. McDonough, G. Piniak, J. VanderPluym, B. Williams, and three anonymous reviewers. The views contained in this manuscript do not necessarily reflect the view of NOAA. This study was funded by the Florida Fish and Wildlife Conservation Commission and the NOAA, National Ocean Service, Center for Coastal Fisheries and Habitat Research.

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