Can we plant seagrass as part of restoration? A proposal, using small plots, volunteers, and feedback loops

Robert Virnstein

Seagrass Ecosystems Analysts, 5200 SW 25th Blvd., #1221, Gainesville, FL 32608

Abstract Since 2009, the Indian River Lagoon (IRL) has lost over half its seagrass due to phytoplankton blooms. The loss was especially high in the north-central IRL and Banana River lagoon—nearly 100% in some segments. Over 190 km^2 of seagrass was lost. One question is what might natural recovery look like? Can we emulate that process to jump-start restoration? Planting that much area is not feasible. The goal is to develop restoration procedures with positive feedback loops—both ecological and cultural. Ecologically, feedback means getting many patches established that subsequently provide a source for new recruits. This initial jump-start is especially important in segments that lost virtually all their seagrass. Culturally, feedback entails involving and training volunteers to plant small patches of seagrass in many places. A few successes promote more participation and thus more success. Recovery will take time, persistence, and some luck. Reducing risk is the key factor. Proposals are made about how to reduce the risk of failure in planting seagrass—over both space and time.

Keywords Feedback loops, Indian River Lagoon, seagrass, seagrass recovery, seagrass restoration, seagrass transplanting

The Need

Seagrasses in the Indian River Lagoon (IRL) are important for the services they provide—for habitat, nursery, water quality, wave buffering, and the regional economy (Virnstein 1999, Steward et al. 2003). Seagrass is the key indicator in the IRL SWIM (Surface Water Improvement and Management) Plan, whose goal is "to support a healthy, **macrophyte-based**, estuarine lagoon ecosystem" [my emphasis] (Steward et al. 2003).

However, following an intense phytoplankton bloom (the "superbloom") of 2010-2011 (Phlips et al. 2014), there was a major loss of seagrass in the IRL (Morris et al. 2021). The loss of seagrass was nearly 100% in the north central IRL and Banana River. Overall, more than half the seagrass cover in the IRL was lost—a total of over 190 km^2, with the mean deep edge of beds retreating over 100 m closer to shore (Morris et al. 2021). Because of recurring green and brown tides following the superbloom, there has been little seagrass recovery and recruitment. Nature is resilient, but might need a jumpstart.

Because seagrass both protects water quality and provides habitat for myriad animals, restoring seagrass will improve overall habitat diversity in the Indian

Corresponding author: Robert Virnstein, seagrass3@gmail.com

River Lagoon. For example, the most species-rich fish communities are found in seagrass beds (Gilmore 1995).

Question: Is it possible to emulate and enhance natural processes by spreading risk of planting failure, both spatially and temporally?

The Challenges

Ultimately for recovery, we need to know and eliminate the cause of the loss—otherwise, any planting effort is futile. The long-term solution will require a reduction in nutrient loading to mitigate phytoplankton blooms. But planting seagrass may provide a short-term jumpstart. Decision support tools are necessary, including spatial planning and suitability indices as reviewed by van Katwijk et al. (2016).

However, it is unrealistic to recover simply by planting. How unrealistic? Planting 190 km^2 at 1-m intervals between planting units (PUs) would require 19 billion planting units. Planting a million PUs a day would take 52 years.

Planting is expensive, typically $80,000 to $200,000/hectare, but up to $800,000/ha when all costs are included over the life of the project; each PU requires 2-4 work-minutes (Fonseca et al. 1998, Fonseca et al. 2000). The track record of planting is mixed.

There is no agreed-upon standardized method; however, Fonseca et al. (1998) provide a comprehensive guide. Typically, rhizome fragments are anchored to the sediment with staples. Although plugs can be successful (Heidelbaugh et al. 2000, Hanisak and Virnstein 2016), plugs are labor-intensive and thus expensive. And taking plugs can be destructive to the donor beds. Large sods are even more expensive and destructive to donor beds, although large sods (up to 11 m^2) were more successful in an open coast environment (Paulo et al. 2019). Despite decades of experience and several reviews, seagrass restoration is still a developing science (Wood et al. 2019). Local knowledge in selecting suitable sites is perhaps the most critical factor.

Initial loss of PUs is sometimes high due to physical processes (waves, currents). Thus staples are often used to hold plants in place long enough for the rhizomes to grow anchoring roots (Fonseca et al. 1998). Currently (as of April 2021), a test is underway in cooperation with Brevard Zoo comparing planting success in 2-m by 2-m plots of *Halodule wrightii* with staples and without staples. Survival of PUs at 2 months was similar, with 33% survival with bamboo staples and 38% without staples. Rapid losses due to grazing or bioturbation are common: by manatees, sea turtles, rays, crabs, and fish. Manatees can uproot seagrass as part of their feeding behavior (Packard 1984). Protecting plants may require caging or fencing, but the logistics of this are expensive, especially for volunteers.

Sufficient source material is often a problem. Shoreline wrack after a storm or extensive bioturbation may be a source, but the material must be fresh. Floating rhizome fragments are a good source, but are abundant only occasionally. Harm to donor beds may be minimized by taking small scattered patches out of a donor bed. "Small" might mean a two-handed grab wiggling rhizomes loose from the sediment or using a pitchfork to loosen and lift and shake off sediment. These small takings should be spaced far enough apart (~1 m minimum) to allow infilling by surrounding rhizome growth. Such techniques result in no long-term impact to donor beds (Williams 1990, Fonseca et al. 1994, Hanisak and Virnstein 2016).

Genetic diversity should be maintained. Local sources or nursery-grown stock from local sources should be used, such as that being grown by K. Tiling at Florida Oceanographic Society and by M.D. Hanisak at FAU's Harbor Branch Oceanographic Institute. There are also commercially grown sources.

We know that seagrass and grazers can co-exist. Eventually, sufficient seagrass acreage will be needed to support grazers *plus* enough remaining to maintain beds. It is difficult to predict how much seagrass is enough to survive in the face of grazing. As an example, in the past, prior to loss of seagrass in 2011, the 8,000 ha of seagrass in Banana River supported up to 1,200 manatees during summer months (Provancha and Provancha 1988). That both manatees and seagrass thrived in Banana River tells us that the 7 ha per manatee was obviously above the carrying capacity. However, it is difficult to predict how much seagrass is enough to survive grazing pressure.

Possible Solutions to these Challenges

Through planting, it is possible to overcome a major weak link in natural recruitment of seagrass. Much natural seagrass recruitment in IRL is by rhizome fragments (Johansson and Nilsson 1993, Morris and Virnstein 2004). But fragments typically float, at least during the day (Hall et al. 2006). These floating fragments are pushed across the Lagoon by the sea breeze. Thus a large proportion of floating rhizome fragments end up on shore, where they die and rot.

The target seagrass species for planting is shoal grass, *Halodule wrightii*. *Halodule* makes up 60-80% of the seagrass cover in the IRL (Virnstein and Morris 1996) and is one of the fastest-growing "pioneer" species in IRL. "Compressed succession" should include other late succession species, like *Syringodium filiforme* and *Thalassia testudinum*, which could be inter-planted later, after the *Halodule* has coalesced.

"Recruitment" here means *new* plants, either from fragments or seeds, but does not include spreading by rhizome elongation. However, recruitment by seeds for these three canopy-forming species is undocumented in the Indian River Lagoon. Therefore, recruitment is primarily by vegetative fragments.

Successful attachment of a rhizome fragment to the sediment requires: (1) production of fragments, often uprooted by manatees, rays, or horseshoe crabs, (2) transport of that fragment to a site suitable for seagrass growth, (3) sinking of the fragment (typically at night), and (4) growth of sufficient roots to anchor the fragment to the sediment. This sequence does happen, but seems like a low probability event. In outdoor tanks, this natural process does happen (Hall et al. 2006). Simply inserting the rhizomes into the sediment long enough for them to grow anchoring roots greatly increases the probability of survival.

Providing sufficient stock and genetic diversity for planting may require raising plants in nurseries. Culturing plants could also provide genetic diversity, an important factor shown to be true for other seagrass species (Williams 2001, Reynolds et al. 2012, 2013). Genetic stock that is a good early colonizer could be used as the dominant genetic stock in plantings. Volunteers could collect planting stock from local beach wrack, but only if it is fresh. All waterfront homeowners should be encouraged to plant a few small plots in front of their homes.

Overcoming the natural recruitment weak link—becoming attached to the sediment in an appropriate location for growth—simply by inserting the roots and rhizome into the sediment is the main path to successful transplanting and recovery, jumpstarting a process that may take a long time if nature were to take its own course.

Scenarios for Scaling up from a Plot to a Bed to Meadows

Planting a small patch is helpful, but how do we restore the 190 km^2 of lost seagrass? How can a small patch be transformed into a bed that can then expand throughout the IRL? One approach is to plant very large patches (hectares?), so that even under heavy grazing pressure, some surviving seagrass remains as a source for bed extension and as a source of new recruits. This large patch approach, i.e. bigger is better, has been advocated (Orth et al. 2006, Bell et al. 2008, van Katwijk et al. 2015) and has had some success, including a 2-acre (0.8-ha) planting in Banana River at a site made shallow with dredged material (pers. comm. L. Thompson, Dixie Crossroads, September 27, 2018).

Rather than expanding spatially by planting larger plots, the proposed alternate strategy is to plant many many small scattered patches far enough apart so that grazers don't find all the patches. An example is provided below (see Figure 1). This strategy is chosen because the goal is not mitigation at one site, but rather restoration to a pre-existing condition. Actually, preservation would have been a more cost-effective strategy than restoration.

As an example (Figure 1), one possible approach would be to plant one hectare (2.5 acres) at 0.5-m intervals, which would require over 40,000 planting units (PUs). However, at the same spacing, this same number of PUs could (1) plant 1,600 2-m by 2-m plots, each of which would be easy for a couple of people to plant a plot in about an hour or (2) plant 8,000 plots of 5 PUs planted in an X pattern (a quincunx), which would be easy for one person to plant a plot in minutes (Figure 2B).

These small X-plots could easily be planted by volunteers, following procedures in a short video on YouTube (https://www.youtube.com/watch?v=gkdxicQTRCg). For this method, one PVC stake could mark the center of the plot; then plant one PU at the center by the stake and one PU each in the four compass directions, or two PUs parallel to shore and two PUs perpendicular to shore. The 0.5-m spacing can be estimated as a forearm length, one cubit (Figure 2B). This layout makes monitoring easy.

This 0.5-m spacing was selected because *Halodule* PUs planted that far apart can coalesce within one growing season (unpublished data from two recent trial plantings). Under ideal conditions, plantings using 1-m spacing can *begin* to coalesce in a full growing season, planted in early Spring (March) (unpublished data).

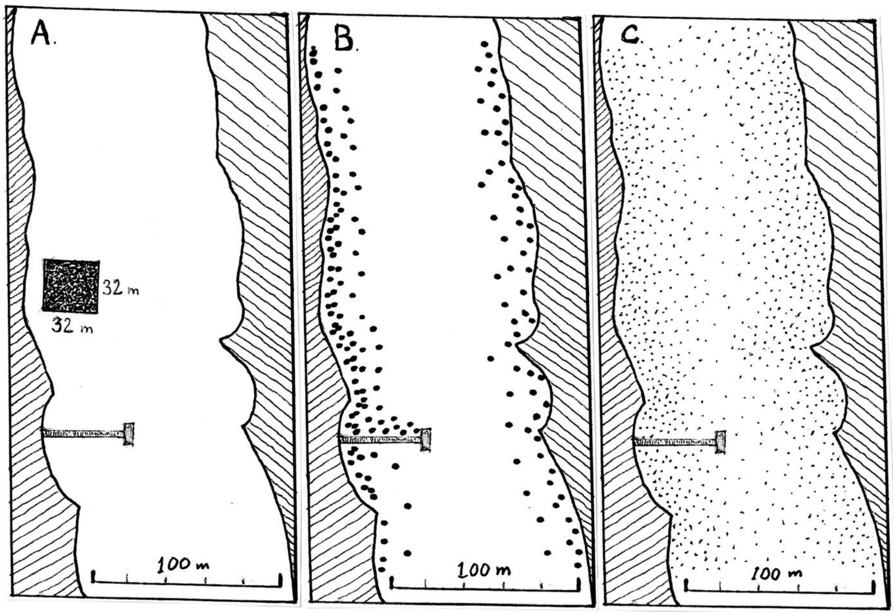

Figure 1. Three planting scenarios, each using 4,225 planting units (PUs) at 0.5-m spacing in a hypothetical 100-m by 300-m section of the IRL. **A**: one big planting plot of 0.1 ha (= ¼ acre). **B**: 169 plots, 2-m by 2-m, each with 25 PUs. **C**: 845 X-shaped plots, each with 5 PUs. Average distance between X-plots is 6 m. All diagrams are to scale; a 50-m long dock is illustrated to help indicate scale.

In the latter example of the X-plots, a 90% failure rate would still leave 800 successful plantings. See Figure 1 for an example of these three different strategy scenarios. The extirpation of some of these small X-plots are low-cost losses. Spread far apart (meters to tens of kilometers), grazers would be unlikely to find all the plots. We would learn through experience what this minimum separation distance is to protect remote patches.

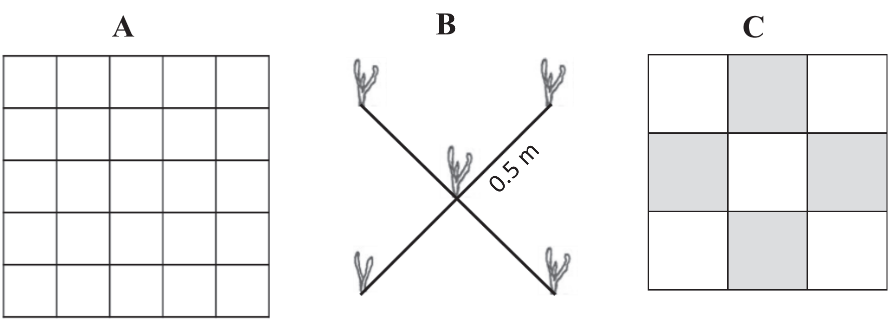

Figure 2. Simple sample blank grids for recording monitoring data. **A**: A 5-by-5 array for the 2-m by 2-m plots. **B**. Diagram of an X-shaped plot. **C**: An X-shaped grid for the X-shaped plots. Shore or compass direction would be indicated. The arms of the X could be oriented perpendicular and parallel to shore, making monitoring easier.

Continuing to plant over extended periods of time (years) would also spread the risk. Some plantings will fail; some may coincide with a good growing season, e.g., during a drought year or a season with high water clarity. Planting would need to continue until seagrass beds are self-maintaining.

The Need to Develop Positive Feedback Loops

Establishing two types of feedback loops is necessary for successful restoration by planting: (1) ecological (Maxwell et al. 2016) and (2) cultural. (1) Ecologically, successful plots produce additional recruitment material (fragments and possibly seeds), which produce more successful plots, which leads to… (2) Culturally (Danielson et al. 2005, Tanner et al. 2014), this feedback loop consists first of recruiting and training volunteers to plant small patches of seagrass in many places. Assuming some plantings are successes, those proud volunteers invite more participants and thus more success, which… The program becomes a culture of success, driven by citizen scientists. Organizing, training, and maintaining a committed volunteer corps will require a concerted management effort. Brevard Zoo and the Marine Resources Council (MRC) already have successful volunteer programs.

Monitoring

Failure is an excellent teacher. Therefore, monitoring is essential for providing feedback on why some sites and procedures fail and some succeed. Planting small plots in specific patterns simplifies monitoring because it's then known exactly where each PU was planted, especially helpful in turbid water with limited visibility. Be prepared to monitor by feel.

The simplest and most important measure in the weeks following planting is percent survival of PUs. Later, spread of PUs could be estimated or measured. A simple blank grid, e.g., a 5 by 5 grid for the 2-m by 2-m plots (Figure 2A) allows easy spatial recording of survival. Over time, simple sketches of cover on this blank grid would provide a "map" of seagrass survival and spread. A similar grid (Figure 2C) can be constructed for recording monitoring results from the X-plots (Figure 2B). The organization managing the volunteers would need to develop simple protocols for site selection and reporting, managing, and promulgating data (e.g., website, Facebook). Volunteers will need to be provided guidelines for site selection, perhaps the single most important step in seagrass restoration.

Definition of "Success"

A proposed short-term working definition of success: at least 50% survival of PUs after 1 year; plus some spread of half of these survivors. Full success would be coalescence of PUs. This short-term working definition is chosen partly to make monitoring simple and achievable, even by volunteers. In addition, once this near-term goal is met, other outside factors may overwhelm later survival and spread—not the fault of planting errors, but of unknown demons.

Over time, methods would be refined and an army of volunteers established. Then, when environmental conditions are more appropriate, planting can quickly move ahead.

So What?

Seagrass recovery appears to need help getting over the threshold of early recruitment (Orth et al. 2006, van Katwijk et al. 2016). Even small successes are important; a little bit of grass is *far* more than zero grass for establishing seagrass itself and for all the services provided by seagrass. Recovery of *Halodule* in the northern end of the Indian River was by rhizome fragments which spread into patches which coalesced to full recovery in 3 years following the complete loss of over 100 ha of previously dense seagrass (Morris and Virnstein 2004).

The trick to providing a jumpstart may be to spread the risk (van Katwijk et al. 2009, Suykerbuyk et al. 2016), both spatially and temporally. Fool the grazers. Catch some opportune times for seagrass planting and growth. Yes, there will be failures. But low-cost simple methods, using volunteers, and employing ecological and cultural feedbacks, is the proposed best way to spread the risk and lead to success.

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