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Effects of common seagrass restoration methods on ecosystem structure in subtropical seagrass meadows

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ABSTRACT

Seagrass meadows near population centers are subject to frequent disturbance from vessel groundings. Common seagrass restoration methods include filling excavations and applying fertilizer to encourage seagrass recruitment. We sampled macrophytes, soil structure, and macroinvertebrate infauna at unrestored and recently restored vessel grounding disturbances to evaluate the effects of these restoration methods on seagrass ecosystem structure. After a year of observations comparing filled sites to both undisturbed reference and unrestored disturbed sites, filled sites had low organic matter content, nutrient pools, and primary producer abundance. Adding a nutrient source increased porewater nutrient pools at disturbed sites and in undisturbed meadows, but not at filled sites. Environmental predictors of infaunal community structure across treatments included soil texture and nutrient pools. At the one year time scale, the restoration methods studied did not result in convergence between restored and unrestored sites. Particularly in filled sites, soil conditions may combine to constrain rapid development of the seagrass community and associated infauna. Our study is important for understanding early recovery trajectories following restoration using these methods.

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1. Introduction

Loss of seagrass resources in coastal ecosystems is accelerating (Waycott et al., 2009), and physical disturbance from storm events, dredging, development, and fishing gear impacts, contributes to this decline (Grech et al., 2012; Orth et al., 2006; Short and Wyllie-Echeverria, 1996). Seagrass soils are critical in supporting key ecosystem functions such as nutrient cycling and benthic remineralization processes (Hemminga and Duarte, 2000; Marba et al., 2006). Physical disturbance to seagrass meadows that disrupts the rhizosphere leads to persistent changes in ecosystem function, including primary production, nutrient cycling, and habitat provision for seagrass-associated organisms (Di Carlo and Kenworthy, 2008; Hammerstrom et al., 2007; Neckles et al., 2005). Disturbance results in alterations to soil structure including loss of organic matter and stored nutrients (Bourque, 2012; Kenworthy et al., 2002). Seagrass ecosystems in locations where boating is popular are subject to frequent and severe physical disturbance when vessels run aground (Dunton and Schonberg, 2002; Kirsch et al., 2005; Sargent et al., 1995; SFNRC, 2008). Accordingly, interest in seagrass restoration has increased in recent decades (Fonseca, 2011; Paling et al., 2009; Treat and Lewis, 2006).

Resource managers attempt to accelerate recovery of disturbed seagrass communities through restoration. Filling grounding excavations, providing a fertilizer source, and transplanting seagrasses are commonly-used restoration techniques (Farrer, 2010; Fonseca et al., 1998; Kirsch et al., 2005; McNeese et al., 2006). Placing soil fill into excavations is intended to prevent erosion and recreate the physical matrix that supports seagrasses and ecosystem functioning (Farrer, 2010; Hall et al., 2012; Hammerstrom et al., 2007; Kirsch et al., 2005). Seagrasses also may be transplanted to accelerate replacement of plant structure and associated functions over natural secondary succession (Lewis, 1987). Because seagrass ecosystems are often nutrient limited (Short, 1987; Fourqurean et al., 1992), applying fertilizer aims to reestablish or augment pools of limiting nutrients. Since the discovery that seabirds will perch on poles emerging from the water and fertilize the seagrasses of south Florida resulting in changes to

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community structure (Fourqurean et al., 1995; Powell et al., 1989), such bird perches have been used as inexpensive low-maintenance fertilizer additions in seagrass restorations in the region (Kenworthy et al., 2000; Farrer, 2010).

For restoration to be successful, ecological attributes of the system such as structure, composition, and function must be reestablished (Fonseca et al., 1996a; Higgs, 1997; Hobbs and Norton, 1996). Once restoration has been implemented, rapid assessments of plant communities are typically used to monitor restoration success (Farrer, 2010; Fonseca et al., 1998; Kirsch et al., 2005; Uhrin et al., 2011). Few studies have assessed ecosystem structure following seagrass restoration for any aspects other than aboveground plant communities (Fonseca et al., 1996a; McNeese et al., 2006; Hammerstrom et al., 2007; Hall et al., 2012; but see Evans and Short, 2005; Di Carlo and Kenworthy, 2008). Analysis of seagrass associated fauna at restoration sites has included studies of infauna (Bell et al., 1993; Sheridan, 2004a,b; Sheridan et al., 2003) and epibenthic fish and invertebrates (Fonseca et al., 1990, 1996b), but only at sites where transplanting was conducted. We are unaware of studies of seagrass infauna community response to restoration activities involving methods other than seagrass transplanting, such as filling excavations or fertilizing restoration sites.

Recent work has shown that soil structure is substantially altered by some restoration practices, especially placing coarse-grained, erosion-resistant fill into fine-grained seagrass ecosystems (McNeese et al., 2006). Filling excavations achieves the objective of stabilizing sites prone to erosion and providing the physical matrix needed to support macrophyte recolonization, but seagrasses and nutrient pools in the soils may be slow to recover.

We sampled macrophyte and infauna communities and soil properties at seagrass restoration sites quarterly for one year following restoration using the filling and nutrient addition methods, alone and in combination, in order to better understand the effects of common restoration actions on seagrass ecosystem structure. We hypothesized that a) restoration actions including fill placement and fertilizer delivery via bird stakes alter primary producer and infauna abundance and soil properties; and b) sites that had been restored either though filling or fertilization more rapidly converged on pre-disturbance conditions than did unrestored sites. Our response variables included structural attributes essential to habitat quality, nutrient storage, ecosystem metabolism, and the structure of the benthic faunal community.

2. Methods

2.1. Study system

This study was conducted on Cutter Bank (25.36715°, −80.26899° in southern Biscayne Bay, a shallow (<3 m) subtropical estuary located at the southeastern tip of the Florida peninsula, USA. Seagrass communities in southern Biscayne Bay are dominated by dense *Thalassia testudinum* meadows typical of oligotrophic tropical seagrass communities throughout the western Atlantic and Caribbean (Zieman, 1982). *Syringodium filiforme*, *Halodule wrightii*, and calcareous green macroalgae are also found throughout this area in lower abundance and with patchy distribution (Bourque and Fourqurean, 2013). A dissolved inorganic nitrogen gradient decreases from west to east in the bay, influenced by freshwater input from canals along the western shoreline (Caccia and Boyer, 2005), and phosphorus limitation of seagrass abundance and productivity is commonly observed in south Florida (Fourqurean and Zieman, 2002). The limited available information on infauna in seagrass soils of this area (McLaughlin et al., 1983; Roessler, 1971) suggests that these communities are typical of those found in subtropical seagrass meadows. Many shallow seagrass shoals (<1 m) in Biscayne Bay, including Cutter Bank, are heavily impacted by vessel groundings, where seagrass has been removed and soil excavated in discrete areas (Bourque, 2012).

2.2. Experimental design

We evaluated ecosystem structure through seagrass community, soil, and infaunal invertebrate community parameters at eighteen individual sites at Cutter Bank. Sites were an average of 34 m^2 in size and 0.4 m in depth, and the maximum distance between sites was approximately 60 m. A factorial design was employed, with soil condition, fertilization, and time as factors. Soil condition treatments included unrestored vessel grounding injuries ("disturbed" sites), restored grounding injuries that were returned to grade with carbonate sand fill from local south Florida quarries ("filled" sites"), and vegetated plots in the undisturbed seagrass meadow ("reference" sites). At each filled site, eleven to 37 cubic meters of sand was placed into excavations as loose fill using a barge-mounted clamshell bucket. The soil condition factor was crossed with a fertilization factor by installing bird roosting stakes into a subset of sites within each three soil condition treatments, henceforth denoted as "disturbed+", "filled+", and "reference+" sites. At each fertilized site, between five and 28 bird roosting stakes were installed on 2-m centers so that the roosting block was approximately 30 cm above the surface of the water at high tide. Three sites were included in each soil condition × fertilization treatment. Soil condition and fertilization treatments were randomly assigned to sites. Note the disturbed sites and the sites that were filled were not recent disturbances, but rather were known to be a minimum of five years old based on knowledge of disturbance features at Cutter Bank (Bourque, unpublished).

Reference and reference + plots for soil and invertebrate parameters were established by delineating 32 m^2 circular plots around randomly selected points in a seagrass-vegetated area of the shoal that showed no signs of recent vessel grounding disturbance. For seagrass community parameters, undisturbed seagrass meadows within a 2 m buffer encircling each disturbed or filled site were sampled for reference conditions. Sites were sampled following implementation of a restoration project that was completed in January–February 2010. For soils and invertebrate parameters, sampling began within a month of restoration completion, and was repeated at 3, 6, 9, and 12 months following restoration (i.e., February, May, August, November 2010 and February 2011). The seagrass community was sampled only at months 0, 6, and 12 months following restoration.

2.3. Seagrass community characterization

To evaluate the status of the macrophyte community at each site, seagrass and macroalgae abundance was estimated within randomly placed 0.25 m^2 PVC quadrats, using a modified Braun-Blanquet (BB) cover-abundance scale (Fourqurean et al., 2001). While many taxa of macroalgae were encountered in our surveys, only the calcareous green macroalgae from the genera *Halimeda*, *Penicillus*, and *Udotea* were common, so we have restricted our analysis of macroalgae data to this group. Ten percent of each site area was sampled.

2.4. Soil core collection and processing

We sampled a suite of twelve soil properties that are indicators of structure and function in seagrass ecosystems, including benthic microalgae (primary production, habitat quality); pH, redox potential, organic matter content, and porewater sulfide (benthic