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The Role of Vegetation in Salt Marsh Restoration

Salt marshes are some of the world's most productive ecosystems and provide valuable ecosystem services such as coastal protection, erosion control, water purification, fisheries resources, carbon sequestration, and recreation value (Barbier et al. 2011). These ecosystem services depend on functions provided by salt marsh vegetation either directly or indirectly. To develop a successful restoration plan, restoration goals must be defined prior to the restoration process. These goals may be to maximize a single ecosystem service, to maximize a suite of ecosystem services, or to return a marsh to an original state. In this report I describe the functions provided by marsh vegetation and discuss the conditions and trade-offs that must be considered to restore these functions. In particular, I focus on the role of vegetation in New England marshes and include comparisons between functions provided by the invasive reed species *Phragmites australis* and the native cordgrass *Spartina alterniflora.*

Role of marsh vegetation in sedimentation and erosion

The role of marsh vegetation as a mechanism for increasing accretion rates, stabilizing soils, and preventing erosion is well documented (Redfield 1965, Howes et al. 2010). Many numerical and empirical models in a recent review by Fagherazzi et al (2012) include vegetation as an important driver of sedimentation rates. Vegetation decreases flow velocities increasing deposition rates of suspended sediments (Leonard & Luther 1995), physically traps sediments, and produces organic matter, which facilitates vertical and horizontal accretion of the marsh surface. Additionally, the dense root and rhizome structure provided by marsh vegetation like *Spartina alterniflora* retains sediments and increases shear strength, which reduces erosion (Howes et al. 2010). However, the effect of vegetation can vary depending on factors including tidal depth (Morris et al. 2002), wave exposure (Möller & Spencer 2002), and vegetation density (Gleason et al. 1979, Leonard & Luther 1995).

Salt marsh vegetation increases marsh platform elevation but it is also dependent on tidal depth (Burdick et al. 1996). An optimum depth exists where plant productivity is maximized at a given elevation. Low elevations can allow native halophytes such as *Spartina alterniflora* to thrive and outcompete less salt tolerant competitors such as *Phragmites australis* (Vasquez et al. 2006). Meanwhile, at high elevations the hydroperiod can decrease, changing sulfide concentrations, water availability, and salinity, which can reduce plant productivity (Chambers et al 2003, Zedler & Kercher 2005). Therefore initial and projected elevations should be considered prior to restoration.

Although marsh vegetation is known to stabilize sediments and dissipate wave energies over a marsh (Möller & Spencer 2002), a recent study by Feagin et al. (2009) uses simulations of erosion to demonstrate that it is soil type rather than vegetation that mediates erosion of marsh edges. The results of this study do not discount the importance of vegetation in stabilizing marsh sediments, but suggests that there is a difference between erosion on the marsh edge and the marsh interior. They found that soil type is a better predictor of erosion than presence of vegetation (Feagin et al. 2009). In particular, soils high with organic matter, low bulk densities, low water saturation, and small particle sizes had lower erosion rates on marsh edges. Feagin et al (2009) suggest that vegetation is most useful at mediating sedimentary marsh processes such as sea level rise, which occur over longer time scales. Although vegetation alone does not directly affect erosion rates on the marsh edge in high exposure areas, vegetation provides a source of organic matter that can improve soil conditions on marsh edges (reference).

Stem densities of *Spartina alterniflora* affect sedimentation rates, where deposition increases non-linearly with increasing stem density (Gleason et al. 1979). Results from a small-scale laboratory experiment suggest that stem densities greater than 54 stems/m^2 have the greatest deposition rates and showed a minimal increase in deposition rates when stem densities were increased to 108 stems/m^2 (Gleason et al. 1979). However, the wave energies used in this experiment were low, with waves only 6 - 10 cm high and the authors point out that washout of sediment and rooted *S. alterniflora* sprigs can occur when wave energies increase. They also suggest that washout can further reduce vegetation abilities to retain sediments if areas of washout are pushed farther back on the creek bank and remain as wrack. In this experiment, sprigs of *S. alterniflora* which were one centimetre in diameter were used, and planted at densities between what is considered feasible for manual planting (27 stems/m^2) and the lower bound of naturally occurring densities in mature *S. alterniflora* stands (108 stems/m^2) (Gleason et al. 1979). These results suggest that if *S. alterniflora* sprigs are planted as part of a restoration strategy, densities of approximately 54 stems/m^2 will yield the effective sedimentation rates for unit of planting effort. Further, planting efforts should be targeted to the interior marsh where wave energies should be lowest.

Marsh vegetation structures animal communities

Marsh vegetation provides structure and refugia in a habitat that would otherwise be a mudflat, indirectly provisioning adjacent coastal fisheries (Barbier et al 2011) and providing habitat for birds (Smith et al 2009). Differences in animal communities between *Phragmites* dominated marshes and *Spartina* dominated marshes have been observed, but the degree to which these differences effect marsh functioning is still unknown. Most studies indicate that nekton communities in *Phragmites* dominated marshes have lower species richness, lower evenness, and overall lower individual species abundances (Roman et al 2002, Gratton & Denno 2005).

In a *Phragmites* removal experiment in Delaware, Gratton and Denno (2005) observed greater species richness and evenness of arthropod communities in *Spartina* dominated reference sites, restored *Spartina* sites, and mixed *Spartina – Phragmites* sites when compared to long-standing *Phragmites* sites. Further, this difference was driven by dominance of herbivorous trophic levels and a reduction in carnivores and detritivores in the long-standing *Phragmites* sites. It is however, unclear how this difference in trophic structures affects marsh functioning.

Evidence for differences in nekton communities is not as strong as for arthropod communities, but similar trends exist—nekton communities are generally more diverse in *Spartina* dominated sites (Buchsbaum et al. 2006, Kimball & Able 2007). Although the biological significance of the difference is unclear, as at least in one case the difference was attributed to species that were infrequently captured in *Phragmites* and *Spartina* sites (Kimball & Able 2007). There are however differences beyond species composition and relative abundances. Able and Hagan (2000) found that while large mummichogs (*Fundulus heteroclitus*) smaller mummichogs (*Fundulus heteroclites*) were more abundant in *S. alterniflora* marshes. These results imply that regardless of any differences in species diversity in *Phragmites* and *Spartina* habitats, a reduction in refugia for small fishes reduces marsh functioning as a nursery.

Response of vegetation to tidal inundation

Restoration of tidal flow to a tide restricted marsh is fundamental to restoring salt marsh functioning and native vegetation (Burdick et al 1995, Roman et al 2002, Smith et al 2009). However recovery rates of native halophytes are highly variable within and across marsh systems. Factors governing recovery rates are still not well defined but include rate of tidal inundation (Roman et al 2002, Smith et al. 2009), hydroperiod (Kimball & Able 2007), water table depth (Warren et al. 2002), soil chemistry (Bart & Hartman 2002, Chambers et al. 2003, Seliskar et al. 2004), and availability of seeds and propagules (Angelini & Silliman 2012). In New England marshes re-establishment of vegetation is complicated by slow rates of native halophyte growth rates and competition with the less salt tolerant, but competitively dominant reed species *Phragmites australis*. Although *P. australis* can tolerate brackish water, when found in soils with pore water salinities greater than 25 ppt, *P. australis* growth is stunted and becomes an inferior competitor to *Spartina alterniflora* (Bart & Hartman 2002, Warren et al. 2002, Smith et al. 2009). Additionally, *P. australis* is more sensitive to high sulfide concentrations, where *S. alterniflora* seedlings have a competitive advantage at sulfide concentrations greater than 0.4 – 0.9 mM (Bart & Hartman 2002, Seliskar et al. 2004)

Given these chemical constraints on *P. australis* rapid restoration of tidal inundation can exterminate *P. australis* and allow native vegetation to recolonize (Roman et al 2002). But if tidal inundation is so great that it submerges all source populations of native vegetation then recolonization is not possible and the threat of erosion increases. An alternative strategy is to incrementally restore tidal flow. From 1997 to 2006, Smith et al (2009) monitored the progress of an incremental flow restoration project in Hatches Harbour, Massachusetts. To allow gradual restoration and maintain natural patterns of zonation and community structure, tidal range was increased incrementally in 1997, 2002, and again in 2004. Although salt intolerant species such as *Spiraea* spp., *Rubus* spp., and *Juncus gerardi* experienced immediate and severe decreases in percent cover (14 – 21%), native halophytes including *S. alterniflora, Salicornia maritima,* and, *Distichlis spicata* experienced either no statistically significant change or only a slight increase in percent cover (1 – 2%), and *Phragmites australis* had no significant change in percent cover

(Smith et al 2009). These results highlight the weakness of incremental tidal flow restoration.

The advantage of the incremental restoration of tidal flow method may be appropriate if it allows maintenance of an intact marsh community to adjust gradually. Some benefits of restoring natural and diverse communities of saltmarsh species include improving sustainability of the restoration project by promoting facilitator species. Hacker and Bertness (1999) experimentally determined that the native grass *Juncus gerardi* modified soil conditions to facilitate growth by three additional grass species, increasing persistence of three upper intertidal species (*Atriplex patula, Iva frutescens,* and *Limonium nashii*). Further, self-facilitation of species such as *S. alterniflora* should increase rates of colonization. *S. alterniflora* self-facilitate by increasing oxygenation of soil, which promotes clonal expansion. Additionally, *S. alterniflora* self-facilitates through a mutualist interaction with the fiddler crab *Uca pugnax* (Bertness 1985). By monitoring such facilitative interactions and incorporating them into a management strategy, chances of restoration success should improve.

Future directions and conclusions

In developing a restoration plan, it is important to consider the initial conditions such as marsh elevation, vegetation community composition, pore water chemistry, and wave exposure, and also to consider how these parameters will change over the course of restoration. The trajectory of changes can determine the level of external or additional maintenance that is necessary to complete restoration. In marshes that are dominated by *P. australis* the choice of incremental restoration of tidal flow can allow persistence of *P. australis*, which may threaten the recovery of *S. alterniflora*. Therefore it may be necessary to remove *P. australis* to succeed in restoration using incremental tidal flow increases. Alternatively if restoration of tidal flow is rapid and immediate, source populations of native vegetation may disappear and recovery of could fail, unless additional measures are taken, such as increasing elevation prior to return of flow, or planting native grasses.

Restoration of salt marsh vegetation is fundamental to restoring ecosystem functions of a marsh, regardless of what restoration goals are defined. There are trade-offs that must be considered when restoring salt marsh vegetation, particularly when choosing between incremental or rapid restoration of tidal flow. However, these trade-offs need to be evaluated in a framework with some uncertainty. With a large range of factors such as marsh elevation and biotic interactions that can complicate recovery it is difficult to identify the key feedbacks moving forward that could reduce the probability of success for a restoration project. It is unclear what the sufficient level of initial effort is required (e.g., How much *P. australis* must be removed? What density of *S. alterniflora* should be planted? What percent cover of *S. alterniflora* should be planted?) and the level of restoration that is required to achieve the functions of interest. These uncertainties emphasize the importance of clearly delineating restoration goals that include benchmarks for success that allow the restoration plan to adjust to uncertainties that may arise.

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