

Restoring coastal wetlands that were ditched for mosquito control: A preliminary assessment of hydro-leveling as a restoration technique

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Received: 1 July 2007 / Accepted: 7 August 2007 / Published online: 18 September 2007
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Abstract The wetlands surrounding Tampa Bay, Florida were extensively ditched for mosquito control in the 1950s. Spoil from ditch construction was placed adjacent to the wetlands ditches creating mound-like features (spoil-mounds). These mounds represent a loss of 14% of the wetland area in Tampa Bay. Spoil mounds interfere with tidal flow and are locations for non-native plants to colonize (e.g., *Schinus terebinthifolius*). Removal of the spoil mounds to eliminate exotic plants, restore native vegetation, and re-establish natural hydrology is a restoration priority for environmental managers. Hydro-leveling, a new technique, was tested in a mangrove forest restoration project in 2004. Hydro-leveling uses a high pressure stream of water to wash sediment from the spoil mound into the adjacent wetland and ditch. To assess the effectiveness of this technique, we conducted vegetation surveys in areas that were hydro-leveled and in non-hydro-leveled areas 3 years post-project. Adult *Schinus* were reduced but not eliminated from hydro-leveled mounds. *Schinus* seedlings however were absent from hydro-leveled sites. Colonization by native species was sparse. Mangrove seedlings were

essentially absent ($\approx 2 \text{ m}^{-2}$) from the centers of hydro-leveled mounds and were in low density on their edges (17 m^{-2}) in comparison to surrounding mangrove forests (105 m^{-2}). Hydro-leveling resulted in mortality of mangroves adjacent to the mounds being leveled. This was probably caused by burial of pneumatophores during the hydro-leveling process. For hydro-leveling to be a useful and successful restoration technique several requirements must be met. Spoil mounds must be lowered to the level of the surrounding wetlands. Spoil must be distributed further into the adjacent wetland to prevent burial of nearby native vegetation. Finally, native species may need to be planted on hydro-leveled areas to speed up the re-vegetation process.

Keywords Mangroves · Salt marshes · Wetlands loss · Tampa Bay · Florida · *Avicennia germinans* · *Laguncularia racemosa* · *Schinus terebinthifolius*

Introduction

Mangrove forests are considered to be imperiled ecosystems at a global scale (Smith 1998; Valiela et al. 2001). Historically, mangrove forests and salt marshes ringed the shorelines of Tampa Bay, Florida. More than 40% of their original area has been lost to coastal development (Simon 1974; Lewis 1977). More recent, and refined, estimates indicate that wetlands loss varies depending on type of wetland and location in the bay. For example in far western Tampa Bay losses approach 50%, whereas in the middle and southern portions of the bay wetlands loss is <20% (TBEP 2000). In addition to direct loss from dredge and fill activities, other human impacts have occurred in these intertidal wetlands. Most noticeable, are ditches dug for mosquito control. In the late 1950s, almost every intertidal

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wetland around Tampa Bay was ditched. This was a common form of mosquito eradication effort that was conducted in coastal wetlands throughout the United States and elsewhere (Clement 1965; Dale and Hulsman 1990; Dale and Knight 2006). Essentially a ditch would be dug from the low intertidal zone into the upper intertidal area of the wetland. The idea was to connect isolated pockets of water with sources of tidal influence. This, it was felt, would allow fish to access the wetland. They would then eat the mosquito larvae and thus control mosquito populations. In Tampa Bay, not only were ditches dug connecting low and high intertidal zones, but lateral or cross ditches were constructed resulting in a checkerboard pattern (Fig. 1).

Spoil from ditch construction was placed in the wetlands adjacent to the ditch creating mound-like features. These spoil mounds are large in area ($\approx 100 \text{ m}^2$), much higher ($\approx 1 \text{ m}$) than the surrounding wetland, and are usually covered with upland vegetation. They interfere with tidal flow and are locations for invasive exotic plants to colonize. In particular they harbor Brazilian Pepper (*Schinus terebenthifolius*) and Australian Pine (*Casuarina equisetifolia*). Both are considered especially noxious (FLEPPC 2005). Removal of the spoil mounds to eliminate exotic plants, re-establish native species and restore natural hydrology, is a restoration priority for environmental managers in the Tampa Bay area (TBEP 2006). Mechanical removal of spoil mounds with earth moving equipment is possible but involves damaging the wetlands as equipment is moved from mound to mound. Recently a new technique has been attempted: hydro-leveling. Initially, the exotic vegetation on the mound is cut and the stumps are treated with a topical herbicide. The cut stems are left in place. Then a high-pressure stream of water is used to blast sediment from the mound into the adjacent wetland and ditch (Fig. 2). This technique was applied to 17.2 ha of wetland at the Gateway Tract (Fig. 3) as part of a mangrove restoration and enhancement project in April 2004. In this paper we present an initial assessment of the efficacy of this method. We examine if hydro-leveling resulted in: a loss of exotic plants; no re-colonization by exotic plants; and, re-establishment of native wetland species such as mangrove (*Avicennia germinans*, *Laguncularia racemosa*, *Rhizophora mangle* and *Conocarpus erectus*) and saltmarsh species (*Batis maritima*, *Salicornia* spp., *Sesuvium portulacastrum*, *Distichlis spicata*, and *Spartina* spp.).

Methods

Study locations

Characteristics of mosquito ditches and spoil mounds were sampled at four locations in western Tampa Bay (Fig. 3):

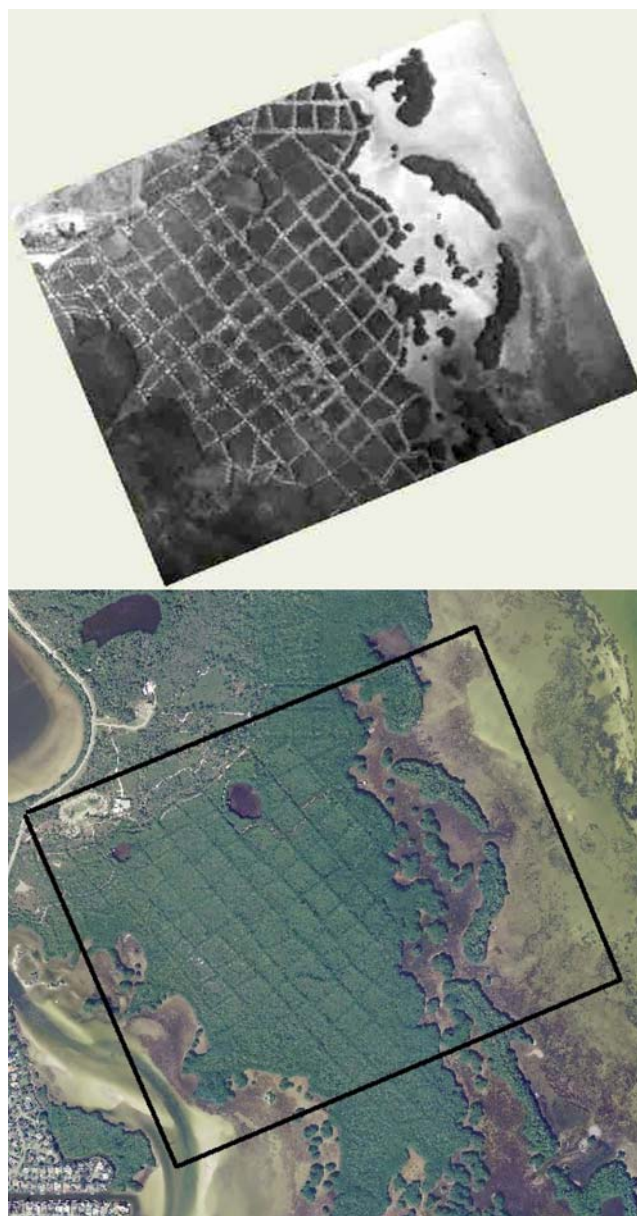


Fig. 1 This figure shows two aerial photographs of the Weedon Island Preserve. The *upper photo* was taken 27 July 1958 and shows the newly constructed mosquito control ditches. The *bottom photo* is from 21 December 2003. The long-term impact of the ditches on the ecosystem is obvious in the checkerboard pattern of the vegetation some 46 years after ditch construction

Mobbly Bayou (MB), Feather Sound (FS), Weedon Island (WI) and the Gateway Tract (GW). Detailed sampling of vegetation was conducted at four sites at the GW site in March–May of 2007. By sampling 3 years after the enhancement we would expect that natural processes of plant dispersal and colonization would have had time to occur. Four sites at GW were sampled (Fig. 4). Two of the four sites sampled at GW were located in areas subjected to hydro-leveling (enhanced) and the other two were in areas not hydro-leveled (control). Furthermore two sites were in



Fig. 2 This photo shows a hydro-leveling crew in action. Water under high pressure is jetted onto the spoil mound and the material is washed into the adjacent wetlands

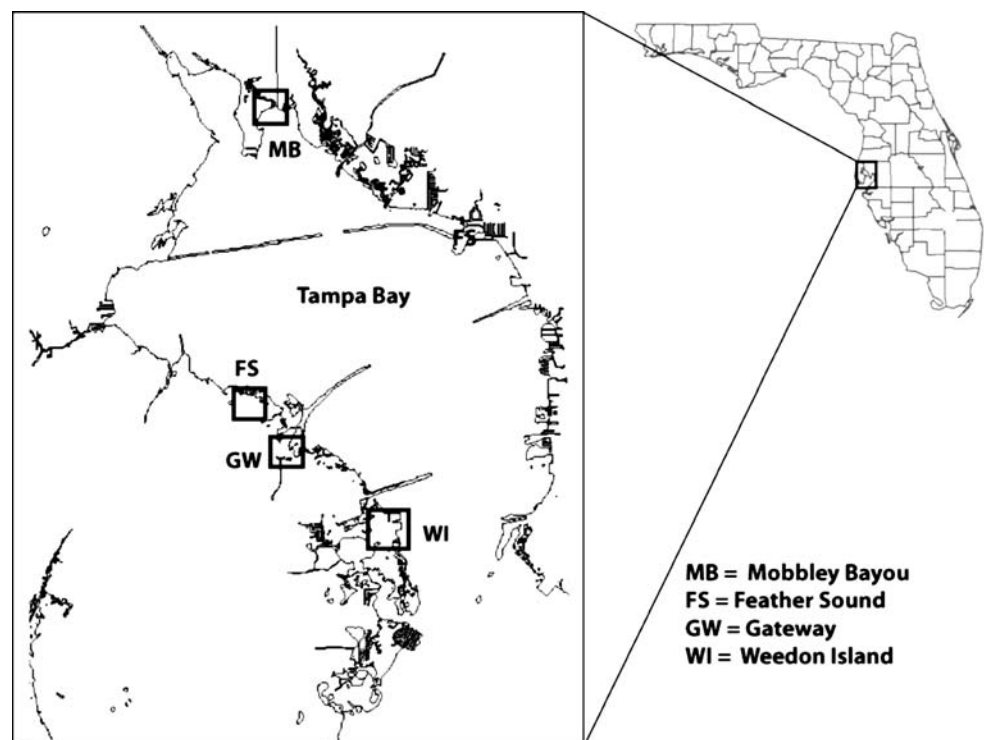
the northern portion of GW and two were in the southern portion (North and South).

Measurements

Spoil mounds and mosquito ditches

The number of spoil mounds and length of mosquito ditches were determined using historical and recent aerial photographs. Historical photographs (1956–1958) were available for three of our study areas (MB, FS and WI).

Fig. 3 Locations of four wetlands along the western shore of Tampa Bay where we measured density of spoil mounds and mosquito ditches. *MB* Mobbly Bayou, *FS* Feather Sound, *GW* GateWay, *WI* Weedon Island



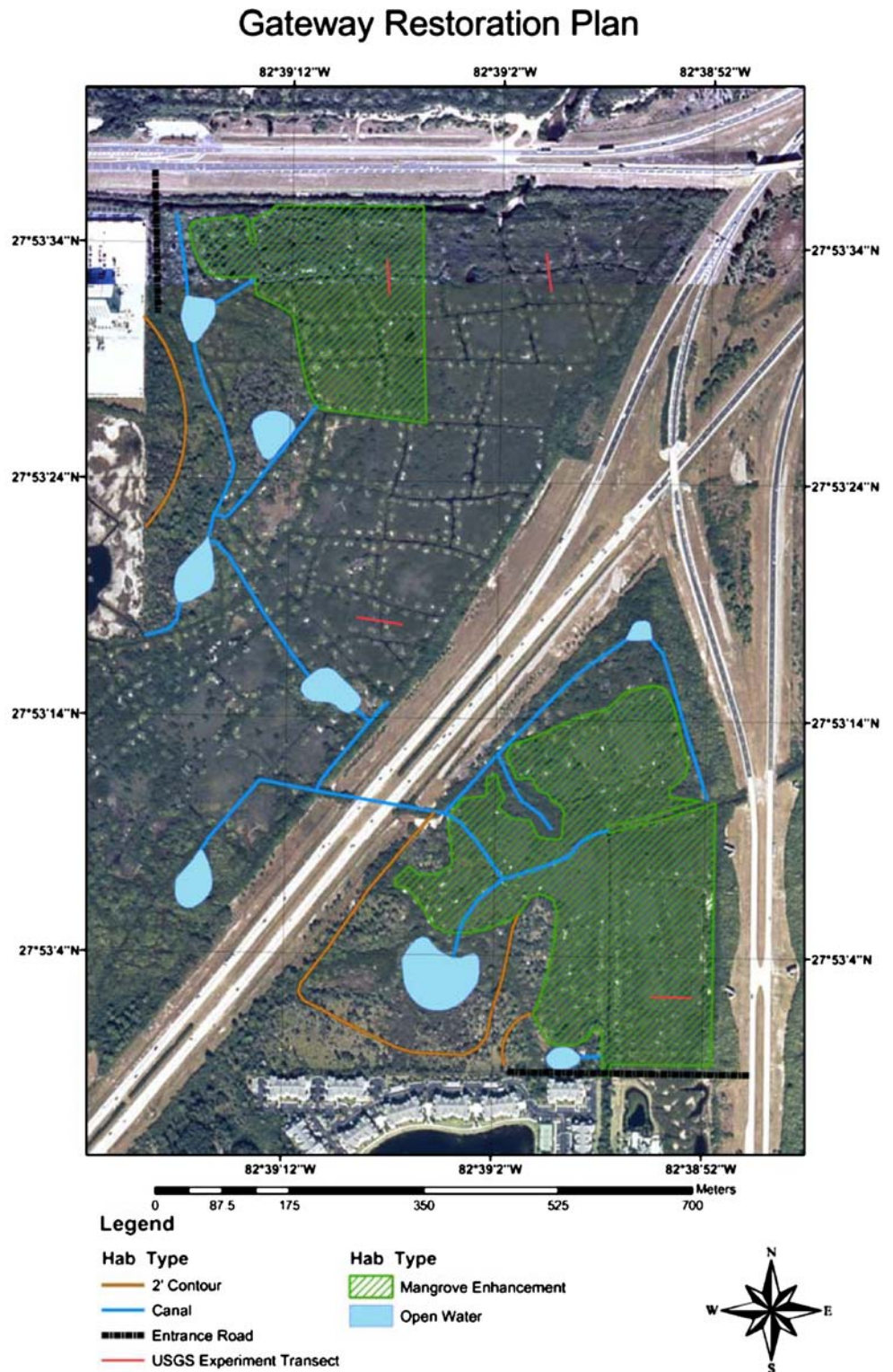
Coincidentally, these were photos were taken during the period of ditch construction. These aerial photographs are housed in the Graber Collection of Aerial Photography housed at the University of South Florida <http://www.lib.usf.edu/public/index.cfm?Pg=GraberCollectionOfAerial-Photography>). Recent aerial photographs (2004) were available for all four of our study sites. These photographs were downloaded from the Florida Department of Environmental Protection's Land Boundary Information System in the form of geo-referenced Digital Orthographic Quarter Quadrangles (<http://data.labins.org/2003/MappingData/DOQQ/doqq.cfm>). By comparing the historic and recent aerial photos, we concluded that no new ditches had been dug in the intervening years (Fig. 1).

For each of the four study locations, five areas were delineated and the number of spoil mounds was counted and length of mosquito ditches was measured. Spoil mound area was measured at the GW location only. Five mounds within each of the four sites at GW were randomly selected. The length and the width of the mounds were measured and their areas calculated assuming an ellipsoidal shape. For the hydro-leveled sites, the outlines of the former mounds were clearly demarcated by the existing mangrove vegetation, both living stems and standing dead stems (see below).

Vegetation at Gateway

All species present on the control and hydro-leveled spoil mounds were recorded, the number of tree stems was

Fig. 4 This plate shows an aerial photo of the Gateway site with restoration plans overlain. US Interstate Highway 275 runs diagonally through the study area. The mosquito control ditches are readily apparent. The whitish dots adjacent and parallel to the ditches are the mounds of spoil. Green hatching delineates areas of mangrove enhancement, totaling 17.2 ha. The four red bars show approximate positions of our four study locations, clockwise from upper left: North Enhanced (NE), North Control (NC), South Enhanced (SE), and South Control (SC)



counted and the presence of all seedlings was recorded. Prior to the hydro-leveling, tree stems on the spoil mounds were cut. In these areas, the number of tree stems present prior to hydro-leveling was estimated based on the number of stumps and identification was based on wood and bark. Some smaller stumps had been washed to the edges of the

mounds during hydro-leveling; these stumps were included in our analysis. By using stumps we could estimate the pre-hydro-leveled tree composition in a manner akin to forensic forestry (Henry and Swan 1974). In the 3 years since the hydro-leveling we found that the stumps were intact with little decomposition. For hydro-leveled mounds we counted

Table 1 Density of spoil mounds (#/ha), area of spoil mounds (m²/ha) and length of ditches (m/ha) in four wetland sites in Tampa Bay, Florida

	MB	FS	GW	WI	OVERALL
Mound Density	24.0±1.7	26.6±4.1	22.6±2.3	28.6±2.2	25.7±1.3
Mound Area	1321±96	1464±226	1245±126	1573±118	1401±141
Ditch Lengths	102±15	139±18	152±16	146±17	135±16

Mean±1SE is given. There were no significant differences among sites. MB=Mobbly Bayou, FS=Feather Sound, GW=GateWay and WI-Weedon Island.

the number of stumps that had re-sprouted (i.e., coppiced). Seedlings were identified and counted in 0.25 m² quadrats. For each hydro-leveled mound, one quadrat was located in the approximate center, one at the edge and one in the adjacent mangrove wetland, for 30 total quadrats. Around the perimeter of the hydro-leveled mounds we counted the number of dead tree stems which were identified based on bark.

Data analyses

One-way ANOVAs were used to examine for differences in the number of spoil mounds and length of ditches per area across the four Tampa Bay wetlands and for mound size comparisons at GW. Differences in seedling abundance were examined using a two-factor ANOVA with Position (mound center, mound edge or adjacent forest) and Site (Gateway North versus Gateway South) as the two factors. Each mangrove species was analyzed separately. Count data were log₁₀ transformed, if necessary, to meet assumptions of normality.

Results

Characterizing mounds and ditches

Neither density of spoil mounds nor length of mosquito ditches varied among the four wetland areas (MB, FS, GW, WI) we sampled ($F_{3,16}=1.01$, $p>0.05$ and $F_{3,16}=1.42$, $p>0.05$, respectively, Table 1). We found approximately 25.7±1.3 mounds/ha across our sites and 135±11 m/ha of mosquito ditches (these and all other values are $X\pm 1SE$). However, at Gateway, detailed measurements of spoil mound area revealed that mounds varied in size among the four study locations within the site ($F_{3,16}=6.59$, $p<0.01$, Table 1). Mounds at the North Enhanced site were largest (86±16 m²), while those at the North Control (31±3 m²) and South Enhanced (46±5 m²) sites were smallest and those at the South Control site were intermediate (56±10 m²). The grand mean mound size at GW is 55±6 m². Assuming that spoil mounds at MB, FS and WI are similar in size we can estimate the area occupied by mounds at

each site by simply multiplying by the estimated mound density at that site. We find that spoil mounds occupy approximately 1,401±141 m²/ha (Table 1), or 14% of the total area.

Vegetation at Gateway

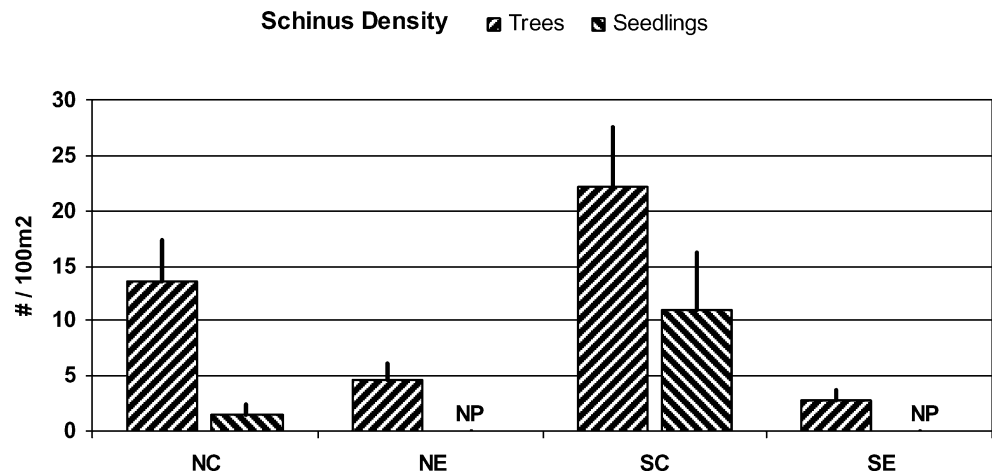
We found 14 species of plants growing on control and hydro-leveled spoil mounds at GW (Table 2). One species was found on all 20 mounds sampled, the invasive exotic *Schinus terebinthifolius*. Adult *Schinus* were present on ALL hydro-leveled mounds. A second exotic species, *Lantana camara*, was found on four mounds, all at the same site. The remaining 12 species we encountered were natives. Examination of the cut stumps of *Schinus* revealed that approximately half had re-sprouted at both the North and South sites at Gateway (46±13% and 52±22%, respectively). However, *Schinus* seedlings were present on Control mounds but not on Enhanced (hydro-leveled) mounds (Fig. 5).

Laguncularia was by far the most abundant mangrove seedling we encountered (Fig. 6) followed by *Avicennia*, and one single *Rhizophora* seedling. This pattern reflects the species abundance in the mangroves at GW. *Laguncu-*

Table 2 Species presence (+) and absence (–) from the four study sites at gateway: North Control (NC), North Enhanced (NE), South Control (SC) and South Enhanced (SE). NA = Not Applicable (mangroves cannot to grow on the spoil mounds)

Plant Species	NC	NE	SC	SE
<i>Schinus terebinthifolius</i>	+	+	+	+
<i>Lantana camara</i>	–	–	+	–
<i>Avicennia germinans</i>	na	+	na	+
<i>Laguncularia racemosa</i>	na	+	na	+
<i>Rhizophora mangle</i>	na	–	na	–
<i>Conocarpus erectus</i>	+	+	+	+
<i>Quercus virginiana</i>	–	–	–	+
<i>Baccharis halimifolia</i>	–	+	+	–
<i>Myrica cerifera</i>	–	–	+	–
<i>Sesuvium portulacastrum</i>	–	–	+	–
<i>Batis maritima</i>	–	+	+	–
<i>Limonium carolinianum</i>	–	+	–	–
<i>Sarcocornia virginica</i>	–	–	–	+
<i>Eupatorium spp.</i>	–	+	+	–

Fig. 5 Density (no./100 m²) of *Schinus* trees and seedlings at the four Gateway study locations. *Schinus* seedlings are not present (NP) at the two enhanced (hydro-leveled) locations



lar and *Avicennia* were both most abundant at the North Enhanced site ($F_{1,24}=4.34$, $p<0.05$ and $F_{1,24}=12.70$, $p<0.01$, respectively). They also had similar patterns of abundance across hydro-leveled mounds. For both species, their seedlings were least abundant in mound centers, and seedling abundance was highest in the adjoining mangrove forest ($F_{2,24}=34.69$, $p<0.01$ and $F_{2,24}=4.74$, $p<0.05$, respectively).

Dead mangroves were present around eight of the 10 hydro-leveled mounds. *Conocarpus* had been cut at both enhanced sites. However, we found that at the North and South Enhanced sites >50% of the cut *Conocarpus* had resprouted ($83.1\pm 14.1\%$ and $53.3\pm 12.9\%$, respectively). A large number of *Laguncularia* had been killed by hydro-leveling at the NE site (22.6 ± 9.5 per mound) and none were found dead at the SE site.

Discussion

Updating estimates of wetlands loss in Tampa Bay

To date, estimates of wetlands loss in Tampa Bay have been made considering only large-scale, and thus very obvious, dredge and fill operations. In the middle portion of Tampa Bay where our study was conducted historical wetlands loss was estimated at $\approx 20\%$ (TBEP 2000). Our measurements show that the spoil mounds occupy $\approx 15\%$ of the area. This loss of wetlands has not been taken into account in earlier estimates. Thus, losses of wetlands in Tampa Bay are larger than previously reported and may be in the neighborhood of 35% for mid-Tampa Bay areas.

Hydro-leveling as a restoration tool

Our results indicate that over a 3-year period, hydro-leveling has not been successful at eliminating invasive species and re-establishing native vegetation in ditched

wetlands. Certain aspects can be corrected by increased training and diligence of the crews that carry out the hydro-leveling. For example, the fact that native species were cut down prior to hydro-leveling indicates that the crews were not adequately taught how to identify tree species. Although the noxious invasive exotic plant *Schinus* was

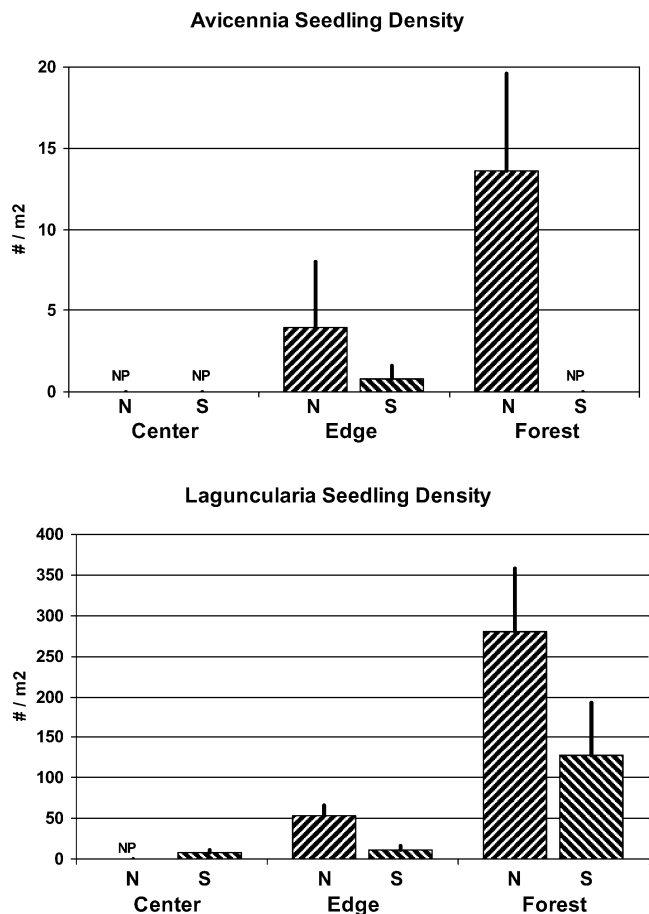


Fig. 6 Seedling density for the mangroves *Avicennia germinans* (upper) and *Laguncularia racemosa* (lower) are shown. Treatment means \pm 1SE are presented and the data have been converted to a per square meter basis. Note the large difference in scale between the two species. N North, S South, NP none present

reduced in number by hydro-leveling, it was not eliminated and the surviving plants can serve as a source for seed dispersal by birds and small mammals (Ewel et al. 1982). This aspect of the restoration can be addressed by repeated applications of herbicide or cutting of surviving stems. The most successful aspect of hydro-leveling was the lack of recruitment by *Schinus*, or any other invasive plant, via seed.

What is most unsettling is the lack of colonization by mangrove or marsh species into hydro-leveled areas. The leveled mounds are surrounded by mangrove thickets, yet the number of mangrove seedlings in the leveled areas is less than one-tenth of their number in the forest. At the NE site, marshes are within 50 m of the leveled mounds. Five marsh species were present at hydro-leveled mounds, but they were in such low numbers as to not have been sampled by our quadrat method. Since mangroves are known to regenerate in canopy gaps (Smith 1987; Sherman et al. 2000) and the hydro-leveled mounds mimic canopy gaps in terms of light level, light is not likely to be a limiting factor for colonization and early growth of mangrove seedlings. Thus, other factors appear to be limiting mangrove recruitment.

Although we did not conduct detailed elevation surveys, it appears that the leveling did not reduce the elevation in hydro-leveled areas to that of the surrounding wetland. Although small differences in elevation (<10–20 cm) can have profound influences on the vegetation structure in mangroves and salt marshes, most species occur over larger elevational ranges. In Australia, ditching for mosquito control has led to mangroves invading adjacent saltmarshes (Breitfuss et al. 2003; Jones et al. 2004), indicating seeds and propagules should be transported through the ditch network. However, our sites are in the higher intertidal zone where small differences in elevation may be more important.

Another possible explanation for failure of marsh plants and mangroves to become established is with the sediment itself. The texture of the surface sediment in hydro-leveled sites was clearly different from that in the mangrove forests. The forest sediments were of a higher organic matter content whereas the hydro-leveled sites were very sandy. More importantly, the hydro-leveled sites had highly compacted sediments. This would impede root development and lower growth rates and survival (Proffitt and Devlin 2005).

Conclusions

Hydro-leveling should be used with caution. For hydro-leveling to be successful coastal managers must ensure that several requirements are fulfilled. Firstly the spoil mounds need to be lowered to the level of the surrounding wetland.

The sediment also needs to be more widely distributed into the adjacent wetlands to ensure that mangrove pneumatophores are not buried. It may also be necessary to plant native species in the hydro-leveled areas to speed up the revegetation process. Lastly, if sediment quality in hydro-leveled sites is not sufficient to promote plant survival, then sediment amendments may be necessary. Continued monitoring of hydro-leveled sites and further applied research are required.

Acknowledgements This research was funded as part the Gulf of Mexico Integrated Science - Tampa Bay Project of the Coastal and Marine Geology Program of the US Geological Survey. Funding from the USGS, Biological Resources Discipline's Terrestrial, Freshwater and Marine Ecosystem Program for the senior author is also gratefully acknowledged. Pinellas County allowed access to their property to conduct the study. P. Kolianos of the Weedon Island Preserve is thanked for her support. D. Hahn and K. Yates provided helpful comments on an earlier version of the manuscript. The 1957 air photo in Fig. 1 is #G23-5800585 from the Graber Collection housed in the University of South Florida Digital Archives. Use of trade and / or product names does not constitute endorsement by the USGS or Pinellas County.

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