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Mangrove at the 18th Hole: Restoration of the Windstar Wetlands

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The word mangrove is derived from the Portuguese word mangue, which means tree, and the English word grove, which means a stand of trees (Odum & McIvor 1990). Genera of mangrove can be traced back as far as 55 million years ago (Raymond & Philips 1983). Making up this group of halophytes (plants that grow in saline soils) are thirty-six species from twelve genera and eight different families (Lugo & Snedaker 1974). Mangrove communities serve as an interface between terrestrial, fresh water and marine environments. They are complex ecosystems which function in nutrient cycling an carbon exchange, and serve as a habitat and breeding ground for a number of marine species. Of the types of coastal vegetation in Florida, mangroves are the dominant type (Ball 1980, Proffitt & Devlin 1991). Over 500,000 acres (202,347 hectares) of mangrove forests remain in the coastal areas of Central and South Florida. Eighty-percent of these are under some type of control for conservation or preservation (Florida Dept. Environ. Prot. website 2001). Prior to the late 1960's, thousands of acres of mangrove forests were destroyed as the result of habitat alterations caused by land development. Natural disturbances have also destroyed or altered these habitats. Since the late 1960's there has been much debate and a heightened awareness of the importance of these communities in maintaining species diversity. As a result, mitigation of mangroves has become an important issue in the state of Florida (Odum & McIvor 1990). One of the earliest mangrove restorations in Florida (1982) was a mitigation project in the Windstar Golf Course and Country Club development in southwestern Florida (C. E. Proffitt, personal communication 2001).

The Windstar Mangrove mitigation site is located in South Naples Florida on Naples Bay adjacent to the Windstar Golf Course. The project was initiated due to the destruction of wetlands during the construction of the Windstar Golf Course and the surrounding multi-family community housing development. In order to complete the construction it was necessary to fill in 5.5 acres (2.2 hectares) of Mangrove wetlands. Mitigation of these losses was attempted through the selection of three sites, totaling 15.4 acres (6.2 hectares) within an existing natural mangrove forest that abuts the Windstar development. The area contained in these sites provided an almost three for one replacement of the destroyed wetlands. Only two of these sites, which will be the focus of this paper, have been the subjects of long-term studies. These sites are 3.3 and 7.8 acres (1.3 and 3.2 hectares) in size (Proffitt & Devlin 1991).

The Windstar Country Club, the owner of the sites, contracted with various consultants in the mitigation effort. Michael Stephen, President and founder of Coastal Engineering Consultants, Inc and Kevin Erwin, an ecologist with Environmental Systems, Inc., designed the project. Coastal Engineering Consultants excavated and prepared the site and Rob Lewis of Mangrove Systems managed the plantings.

Before mitigation, the sites contained mounds of dredge spoil from Naples Bay that had become infested with Australian pine (*Casurina litoria*) and Brazilian pepper (*Schinus terebinthifolius*). Mangrove forests adjoining this area were used as reference sites. Although the exact age of the forests was not known, they were believed to be at least fifty years old because of their presence in aerial photographs from the 1940's. These forests, which have a total area of approximately 98.8 acres (40 hectares), consisted primarily of three species of mangrove: *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove) and *Laguncularia racemosa* (white mangrove). *R. mangle* was the predominant species followed by *A. germinans* and finally *L. racemosa*, which could be found only occasionally except on fringe areas facing the open sites containing the dredge spoil. The increased amount of light available in fringe areas may have been responsible for the larger numbers of *L. racemosa* (Proffitt & Devlin 1991, McKee & Faulkner 2000).

Description of Mangrove Species

Red mangrove trees (*Rhizophora mangle*) have aerial or prop roots that originate from the lower part of the stem and drop roots, which emanate from the branches. These roots have the ability to remove salt from seawater before it is taken into the vascular system of the plant. Also present is a shoot system that allows new trunks to form in response to environmental perturbations (Odum & McIvor 1990). *R. mangle* can reach the height of 25 meters. They have perfect flowers that are usually wind-pollinated but can be pollinated by insects. The seeds of *R. mangle* can be from 20 to 30 cm long and have the ability to float and also germinate before leaving the tree. Seedlings are shade tolerant but may appear stunted under a canopy. *R. mangle* can be found near the water's edge and throughout the intertidal zone. An intertidal zone is the region between the high and low tide marks (Proffitt & Devlin 1991, Odum & McIvor 1990).

Black mangroves (*Avicennia germinans*) have pneumatophores that shoot up from the roots and may reach several centimeters above the soil line. The trees themselves can reach heights of 25 meters. The flowers are perfect and insects are the usual pollinators. Seeds of *A. germinans* have embryos that emerge from the seed coat before leaving the tree and seedlings that are somewhat shade tolerant. Clumps of trees may form via underground shoots and are not found in intertidal zones but are found at the waters edge. *A. germinans*, because of its ability to resprout from the root system, suffers less mortality when subjected to cold, in comparison to *Rhizophora mangle* or *Laguncularia racemosa* (Proffitt & Devlin 1991, Odum & McIvor 1990).

The white mangrove (*Laguncularia racemosa*) is often an early colonizer after a site has been disturbed (Tomlinson 1986). They can be found in any part of the intertidal zone. They may or may not develop pneumatophores depending on environmental conditions and can reach 15 meters or more in height. The flowers, which are primarily insect pollinated, are either perfect or imperfect. Abundant small seeds are produced which may or may not be viviparous. The seedlings are not shade tolerant. Floating seeds are the primary means of dispersal (Proffitt & Devlin 1991).

Ecology of Mangrove Communities

Mangrove forests are found in intertidal zones along tropical coastlines (McKee 1995). They provide a number of functions to estuarian communities. These functions include the production of organic matter, the cycling of nutrients, shoreline stabilization, carbon exchange, and the establishment of food webs (McKee & Faulkner 2000). The food webs established by mangroves are largely driven by the consumption of decaying leaf litter (McIvor & Smith 1995). Mangroves also serve as breeding, feeding and nursery grounds for a wide range of marine life (Imbert et al. 2000). Florida's sport and commercial fisheries depend on the net production from mangroves. Factors that affect the degree and efficiency of nutrient cycling are tidal inflows and outflows, oxygen supply, water and soil salinity, upland water run off and the presence of marine fauna (Lugo & Snedaker 1974). Although not a major contributor to detritus processing, the primary herbivore in Florida mangrove communities is the coffee bean snail (*Melampus coffeus*) (McIvor & Smith 1995).

Throughout Florida and the Caribbean the predominant mangrove species are *Rhizophora mangle*, *Laguncularia racemosa*, and *Avicennia germinans*(Proffitt & Devlin 1991). The distribution of mangrove species on a site may be a function of propagule size. *L. racemosa* and *A. germinans* have smaller propagules (3 – 4 cm) and are more likely to be found in the higher part of the intertidal zones. Conversely, *R. mangle* have larger propagules (20-30 cm) and appear in the lower part of the intertidal zone. Since mangroves germinate before they are released from the parent plant, use of the word propagule is a more appropriate way to refer to the offspring than seed (Odum & McIvor 1990).

Mitigation

In fall of 1982 vegetation on the dredge spoil mounds was removed and the mounds were scraped down to from .8 to 1.9 feet NGVD (.24 to .58 meters) in an attempt to lower the elevation to allow for natural tidal flow and to re-expose original mangrove soils present before the dredge spoil was deposited. Narrow channels were dug to provide a means of tidal flushing (Proffitt & Devlin 1991). One of the most important features of a mangrove community is water fluctuation, including both tidal and fresh water runoff. Because of water fluctuations, hydrogen sulfide and salts are flushed from the mangrove community while nutrients and clean water are transported in (Odum & McIvor 1990).

Although the target community was one which mimicked the natural forests that surround the sites, *Rhizophora mangle* was the only species to be planted as part of the mitigation. Seventy thousand propagules were hand planted in pairs on one-meter centers. Propagules from the other two species were expected to migrate through natural dispersal mechanisms into the site from the surrounding mangroves. Both *Laguncularia racemosa* and *Avicennia germinans* have small propagules that float and are easily transported by water flow into and out of the restoration site (Proffitt & Devlin 1991). After the initial mitigation there was no ongoing management of the sites.

Reforestation

Eight months after the planting of *Rhizophora mangle*, Michael Stephen, from Coastal Engineering Consultants, visually estimated that more than 90% had survived along with the additional arrival of *Avicennia germinans* in a variety of areas on the sites (Stephen 1984). In 1986, four years after the initial planting, it was reported that about 85% of the original plants had survived with little or no additional increase in the population of *R. mangle*. There was also an approximate two acre area at the center of the site where propagules of *R. mangle*, which had been planted below 1.0 foot NGVD (.3 meters), had died leaving exposed mud flats. *Laguncularia. racemosa* had dispersed to and established in the mid elevations on the site. *Avicennia germinans*was present and must have also dispersed to the site from adjacent areas, although in low numbers (Proffitt & Devlin 1991). The establishment of *L. racemosa,* which is intolerant of shade, can be expected to occur in the initial stages of reforestation when a canopy has not yet developed (Ball 1980). Also, the time it takes for *L. racemosa* to establish roots is five days compared to fifteen for *R. mangle* which would give it an early competitive advantage (Odum & McIvor 1990).

In 1989 (7 years post planting) the vegetation of the sites was again surveyed using a variety of measures. Aerial photos showed that between 71 and 85% of the three areas were forested with mangroves. Sea grass (*Ruppia maritima*) and green algae (*Acetaubularia sp*.) had moved into locations that contained open water (Proffitt & Devlin 1991). Sea grass ecosystems are considered to be one of the most productive in terms of being a food source, providing habitat, nutrient stripping and improving water quality (Coppejans et al. 1992).

Numbers of *Rhizophora mangle* had not changed significantly since 1986 and any increase in numbers was conjectured to have been the result of propagules that had entered through the tidal channels, since higher concentrations of this species aggregated around these channels. *L. racemosa*, on the other hand, was found in numbers that were ten times as great as *R. mangle* (Proffitt & Devlin 1991). The source of the propagules necessary for such large increases in this species was probably the canopy that overhung the perimeter of the mitigation site. The seeds of *Laguncularia racemosa* are produced in great quantity. *Avicennia* germinans was still present in small numbers on the upland areas. Mean heights of R. mangle ranged from .86 to 2.92 meters (2.8 to 9.6 feet), L. racemosa from .84 to 2.40 meters (2.8 to 7.9 feet) and A. germinans from .72 to 2.38 meters (2.4 to 7.8 feet). The stunted growth may have been due to extended periods of low rainfall, which may result in excessive salinity and high sulfide levels in the soil (Proffitt & Devlin 1991).

The vegetation survey was done again in the year 2000. At this time significant changes had taken place. Around 1996 a large number of *Laguncularia racemosa* began to die. The cause or causes are unknown but there are a number of possibilities, including nutrient problems. The numbers of *L.racemosa* were still significant enough to ensure that it would continue to have a presence, although diminished, on the sites. Both *Rhizophora mangle* and*Avicennia germinans* were doing well, with *R. mangle* more abundant in the flushing areas and *A. germinans* in the inner areas. Although the mangroves were still much shorter than the reference forests, when comparisons were made in terms of biomass, the mitigation areas, due to plant density, were approximately equal to the natural forests. The relative order with regard to dominant and secondary species was beginning to more closely align with that of the reference site. In the reference site, *R. mangle* was the dominant species followed by *A. germinans* and *L. racemosa* respectively. Only two of the major understory species (*Batis spp*. and *Sesuvium spp.*) found in the natural mangroves have dispersed to the mitigation sites. Original estimates for the length of time that it would take for the mitigation site to look similar to the natural forest was approximately 20 years. According to C. E. Proffitt, who is one of the scientists who have worked on these sites since 1989, 60-70 years may be needed for the restoration to attain similar morphology and function to that of the reference site (C. E. Proffitt, personal communication 2001).

Return of Biogeochemical Function

Carbon transfer, nutrient cycling, organic matter production and the development of food webs are functions that are important in mangrove ecosystems (McKee & Faulkner 2000). It is the return of these functions, which are an integral part of the target community that will determine whether the mitigation project is a success. From November of 1996 through November of 1997, Karen McKee and Patricia Faulkner of the Wetland Biogeochemical Institute at Louisiana State University, Baton Rouge, monitored soil condition, leaf fall and root production, leaf and root degradation in litter bags, and leaf consumption by macrofauna on the Windstar mitigation site (McKee & Faulkner 2000).

The soil bulk density of the restored site was higher than the natural forest's (0.68 $\pm$ 0.05 vs. 0.2 $\pm$ 0.01 g/cm3) because remnants of dredge spoil had become incorporated and there was also some compaction caused by the equipment used for excavating the site. Organic matter was lower than the natural forests (11 $\pm$ 2 vs. 47 $\pm$ 3%), which was expected because of the age of the reforestation. Not enough time had passed to develop a significant organic layer. The soil was found to be hypersaline as compared to the reference site, which was probably due to inadequate flushing caused by sediment build up in the flushing channel. Restricted flushing could have also led to more reducing conditions (anaerobic), which additionally drove sulfide concentrations higher. This combination of conditions could have led to slower growth rates for mangroves in the mitigation site (McKee and Faulkner 2000). Although saline and sulfide levels were higher compared to the reference site, the levels were within the range of other natural mangrove forests in Florida. Soil pH was comparable to reference sites. Because of their correlation with the amount of organic matter in the soil, carbon and nitrogen levels were lower when compared to the reference site. As organic matter levels rise, carbon and nitrogen levels are also expected to rise (McKee & Faulkner 2000).

Total carbon deposition was similar between comparable zones in the restoration site and the reference site. Carbon deposition was calculated by multiplying the measured amount of annual leaf fall and root production per unit area by the estimated average carbon content. The deposition of carbon is an important measure in determining the return of function to a mangrove ecosystem. The decomposition of carbon is the driving force in carbon and nutrient cycling (McKee & Faulkner 2000). Leaf and root material degraded much slower at the restoration site than the natural forest. Influencing the reduced turnover of organic matter is the reestablishment of microbial and macrofaunal detrivores. The presence of macrofauna such as pulmonate snails (*Melampus coffeus* 'coffee bean snail') was significantly less on the mitigation site. Anaerobic conditions primarily caused by inadequate tidal flushing may have been responsible for the variation of the reestablishment and activity of both microbial and macrofaunal detrivore populations (McKee and Faulkner 1990).

Conclusions

What McKee and Faulkner, 2000 found in their study comparing the Windstar mitigation and reference sites was that Windstar was not functioning at the same level and much of this was attributable to hydrologic problems, specifically inadequate tidal flushing. Stagnant water and anaerobic conditions were the result, causing reduced carbon and nutrient cycling. The reestablishment of populations of both macrofaunal and microbial detrivores were inhibited. Proffitt and Devlin, 1991 also attributed much of the slowed progress in reforestation to this same hydrologic problem. High saline and sulfide concentrations reduced mangrove growth as well as the production of organic matter in the soil. The irony here is that to correct the problem would not be costly nor would it take much time. What needs to be done is to clear sediment from a ten foot section of the flushing channel (C. E. Proffitt, personal communication 2001).

Despite the presence of these problems, the effects are not devastating to the restoration site. Should the Windstar mitigation be considered a successful restoration? For seventeen years it has continued to evolve, gaining more and more of the function and form of a natural mangrove with no additional management. The levels of carbon and nutrient cycling are within the normal range for mangrove forests of similar age. Of course, the situation would be much improved if the flushing channel were cleared, but all indications are pointing toward continued progress.

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