

## IMPORTANT CONSIDERATIONS TO ACHIEVE SUCCESSFUL MANGROVE FOREST RESTORATION WITH OPTIMUM FISH HABITAT

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### ABSTRACT

Mangrove forest restoration projects commonly fail to achieve significant plant cover for two reasons: because there is a misunderstanding of mangrove forest hydrology, or, acceptance of the false assumption that simply planting mangroves is all that is required to establish a fully-functional mangrove ecosystem. Even restoration projects that meet a restoration goal within 3–5 yrs often fail to provide adequate habitat for fish and invertebrates. Here we discuss how fish and mangrove ecosystems are coupled in time and space, offer several restoration strategies that match these couplings, and provide simple sequential checklist of design tasks to use to prevent most failures. Tidal hydrology must be carefully designed to incorporate fish habitat, including tidal creeks, to provide access and low tide refuge for mobile nekton because the mangrove forest floor is generally flooded by tidal waters less than 30 percent of the time. A fully successful restoration design must mimic tidal stream morphology and hydrology along an estuarine gradient across a heterogeneous mixture of mangrove ecosystem communities.

Mangrove ecosystems currently cover 146,530 km<sup>2</sup> of the tropical shorelines of the world (FAO, 2003). This represents a decline from 198,000 km<sup>2</sup> of mangroves in 1980, and 157,630 km<sup>2</sup> in 1990 (FAO, 2003). These losses represent about 2.0% per year between 1980–1990, and 0.7% per year between 1990–2000. These figures show the magnitude of mangrove loss, and hence the magnitude of mangrove restoration opportunity, presented by areas like mosquito control impoundments in Florida, USA (Brockmeyer et al., 1997), and abandoned shrimp aquaculture ponds in Thailand and the Philippines (Stevenson et al., 1999).

There are a multitude of opportunities to restore mangrove forests, and reasons to do so. The reasons are often based on fish habitat value, but include others such as direct wildlife use and dependence on fisheries production as a source of food. Here we discuss the basis for the fish—mangrove coupling and restoration efforts meant to restore these habitats. We offer several restoration strategies that match these couplings, and provide a simple sequential checklist of design tasks to be used to prevent most failures.

### COUPLING OF FISH AND MANGROVE HABITATS

We have previously written about the value of mangroves as habitat for fish and invertebrates (Gilmore et al., 1983; Lewis et al., 1985) and have noted the pioneering work of Heald (1971), Odum (1971), and Odum and Heald (1975) in Florida. Wolanski and Boto (1990) looked at similar issues with regard to specific mangrove forests in Thailand, Brazil, Malaysia, Japan, West Africa, and northern Australia and noted that “mangrove forests are a highly productive and valuable marine ecosystem.” Daniel and Robertson (1990) state that “[C]omparisons of the densities of fish and Old World mangrove sites have generally supported the contention of a nursery ground

function for mangrove habitats..." but note that "...there is often high variance in the nursery ground value of mangrove habitats in any one region."

While the controversy about the role of mangrove forests as "nursery habitat" for fish and invertebrates continues (Sheridan and Hays, 2003; Manson et al., 2005), it is generally accepted that mangroves and adjacent nearshore habitats provide important coastal habitats for fish and invertebrates, as well as coastal wildlife species that depend on mangrove forests for both habitat and food resources, such as wading and seabirds, crocodilians, monkeys, and even large mammals such as tigers (Saenger, 2002). A good example of this is the Roseate spoonbill in Florida (*Ajaia ajaja* Linnaeus, 1758) about which Lorenz et al. (2002) state "...small fishes of the orders Cyprinodontidae and Poeciliidae appear to be the primary dietary items."

As noted in Lewis (1992), declines in both the commercial and recreational harvests of fishes have been attributed to overharvesting, water pollution, and habitat loss (Stroud, 1983; Royce, 1987). In response to these declines, various fishery management tools have been proposed and implemented. They include legally limiting harvests (by size and number), closing seasons, limiting entry, stocking from hatcheries, and enhancing fisheries, the latter most often defined as the creation of artificial reefs (Royce, 1987).

Fish and invertebrate habitat protection is often discussed in relation to declining fishery harvests, but restoration of degraded or lost coastal wetland habitats has only recently been recognized as having great potential as a cost-effective fishery maintenance and restoration strategy (Lewis, 1992; Benaka, 1999).

Mangrove communities worldwide often contain a suite of fish with widely varying life history strategies. A few "resident" species spend their entire lives reproducing and feeding within mangrove habitats. These fish are often small and numerous, numerically dominating the mangrove fish fauna (Blaber, 1997). Ephemeral visitors to mangrove communities, or "transients" typically utilize mangrove systems to forage, or to seek refuge from predation. Mangrove ecosystems are sought as nursery sites for many transient species, such as the elopids, megalopids, centropomids, and lutjanids, which are major tropical estuarine predators as adults. These species enter the mangrove system as small larvae or early juveniles, often grow rapidly, and leave the system before maturing as top predators in the adjacent estuary. The most common transient omnivorous primary consumers are represented by mugiliids, clupeids, sparids, and gerreids (Gilmore and Snedaker, 1993). The omnivorous/detritivorous transient fishes may use the mangrove system as a nursery ground, but they also enter these systems in large numbers as adults to feed on the abundant primary producers, algal/bacterial conglomerates, and detritus that is abundant in tropical mangrove habitats.

Resident species that reproduce and feed primarily in mangrove forest ecosystems are typically micro/macro-consumers, herbivores or omnivores (Table 1). This group typically consists of small fishes with highly variable diets, often capable of consuming algae, cyanobacteria, and micro-invertebrates. In the tropical western Atlantic, resident mangrove species typically consist of cyprinodonts, fundulids, rivulins, poeciliids, eleotrids, and gobiids. To remain within mangrove ecosystems throughout the year, a resident species must have eco-physiological capabilities that allow it to survive the extreme physical conditions characteristic of mangrove habitats: periodic dewatering, low dissolved oxygen, high sulfide levels, extremes of high temperature, and salinity variation. Resident mangrove forest species can typically with-

Table 1. Typical east Florida restored mangrove ecosystem fish community: common species of a total of 93 captured in 5,731 collections at 326 sites in the Indian River Lagoon, Florida. Species are divided into residential and trophic groups from data collected simultaneously in three separate barrier island mangrove systems for 24 hrs every 2 wks over 2 yrs.

	Biomass		No. Individuals	%
	Wet weight (g)	%		
Omnivores grazing on detritus, algae, cyanobacteria, micro and macro invertebrates				
<i>Cyprinodon variegatus</i>	253,700.16	57	405,944	41
<i>Poecilia latipinna</i>	146,412.94	32	234,495	24
<i>Gambusia holbrooki</i>	50,993.30	11	350,769	35
Total residents	451,106.40	49.3	991,208	95
Mangrove transient species				
Top predators feeding on fish and macro invertebrates				
<i>Centropomus undecimalis</i>	5,1487.77	44	12,431	53.0
<i>Elops saurus</i>	25,442.41	22	10,279	44.0
<i>Megalops atlanticus</i>	22,649.31	20	408	2.0
<i>Lutjanus griseus</i>	16,544.94	14	193	0.8
Total transient predators	116,124.43	12.7	23,311	2.2
Omnivores grazing on detritus, algae, cyanobacteria as well as micro and macro invertebrates				
<i>Mugil cephalus</i>	283,754.38	81.0	21,184	74.1
<i>Mugil curema</i>	564,66.10	16.0	3,064	10.7
<i>Brevoortia smithi</i>	935.22	0.3	1,544	5.4
<i>Diapterus auratus</i>	1,596.04	0.5	1,612	5.6
<i>Archosargus probatocephalus</i>	4,934.83	1.4	169	0.6
<i>Gerres cinereus</i>	806.74	0.2	1,033	0.4
Total transient omnivores	348,493.31	38.1	28,606	2.7
Total fish	915,724.14		1,043,125	

stand major variations in physical parameters: water temperature, salinity, pH and dissolved oxygen (Harrington and Harrington, 1961; Gilmore, et al., 1982). Transient species such as tarpon, *Megalops atlanticus* Valenciennes, 1847, and common snook, *Centropomus undecimalis* (Bloch, 1792), have adaptations that allow them to withstand low dissolved oxygen conditions and variable salinity regimes characteristic of mangrove ecosystems (Peterson and Gilmore, 1991).

During the 1950s and 1960s the majority of wetland mangrove habitat on the central east coast of Florida between latitude 27°00' and 29°00' N, approximately 225 coastal km, was impounded to control mosquito populations. Impounding destroyed thousands of hectares of mangrove forest habitat and caused significant perturbation to the mangrove ecosystem and its dependent biota.

The first studies implemented to determine the influence of impounding mangrove ecosystems on associated fish communities were conducted in the 1950s by Harrington and Harrington (1961, 1982). As the first study to document and suggest positive restoration measures Gilmore et al. (1982) demonstrated that even though impoundments destroyed thousands of hectares of fish habitat, these habitats could be restored for fish use through simple tidal reconnection (hydrologic restoration; Brockmeyer et al., 1997). In fact, tidally connected ditches dug to produce impoundment dikes were found to offer new habitat that mimicked tidal creeks, thus allowing

water to remain in the wetland during low water periods, offering more habitat to transient species such as common snook and striped mullet, *Mugil cephalus* Linnaeus, 1758.

As an example, fish fauna data from pre- and post-impoundment of a restored mangrove habitat show that hydrologic restoration restored transient fish communities, previously precluded from the mangrove wetland by impoundment dikes (Table 2). Invertebrate and vegetative communities were also restored through the restoration of tidal access and natural plant succession. Tidal connections to adjacent estuary restored biological transport of biomass from the mangrove wetland to the adjacent estuary and allowed recruitment to the mangrove wetland of juvenile transient species that normally utilize this habitat as nursery habitat (centropomids, elopids, megalopids, lutjanids, and mugiliids; Gilmore 1987a,b).

Extensive impoundment and subsequent restoration of mangrove forest wetlands throughout coastal east Florida allowed researchers to demonstrate the direct value of mangrove restoration by hydrologic restoration on fish communities, particularly

Table 2. Comparison of the east Florida mangrove fish fauna before and after restoration of a 26 ha mangrove wetland ecosystem, Round Island, Indian River County, Florida. These data were collected from 1955–1968 by Harrington and Harrington (1961, 1982) and from 1978–1986 by Gilmore et al. (1982) and Gilmore (1987a). Pre-impoundment collections were from 10 September 1956 to 17 October 1956 and post-impoundment collections from September 1956 to October 1965 and from September 1984 to August 1986.

	Pre-impound.		Post-impound.		Restored	
	Harrington and Harrington, 1961		Harrington and Harrington, 1982		Gilmore et al., 1985	
	No. Individuals	%	No. Individuals	%	No. Individuals	%
<b>Mangrove resident species</b>						
Omnivores grazing on detritus, algae, cyanobacteria, micro and macro invertebrates						
<i>Cyprinodon variegatus</i>	1,986	40.0	235	25	258,597	41.0
<i>Poecilia latipinna</i>	1,215	25.0	400	43	160,317	26.0
<i>Gambusia holbrooki</i>	1,769	36.0	300	32	210,080	33.0
Total residents	4,970	76.0	935	100	628,994	94.0
<b>Mangrove transient species</b>						
Top predators feeding on fish and macro invertebrates						
<i>Centropomus undecimalis</i>	172	38.0	0	0.0	4,005	53.0
<i>Elops saurus</i>	33	7.0	0	0.0	8,849	44.0
<i>Megalops atlanticus</i>	254	55.0	0	0.0	316	2.0
<i>Lutjanus griseus</i>	0	0.0	0	0.0	34	0.8
Total transient predators	459	7.0	0		13,204	2.0
Omnivores grazing on detritus, algae, cyanobacteria as well as micro and macro invertebrates						
<i>Mugil cephalus</i>	1,124	100.0	0	0.0	17,856	74.1
<i>Mugil curema</i>	0	0.0	0	0.0	3,064	10.7
<i>Brevoortia smithi</i>	0	0.0	0	0.0	78	5.4
<i>Diapterus auratus</i>	0	0.0	0	0.0	102	5.6
<i>Archosargus probatocephalus</i>	0	0.0	0	0.0	15	0.6
<i>Gerres cinereus</i>	0	0.0	0	0.0	328	0.4
Total transient omnivores	1,124	17.0			21,443	3.0
Total fish	6,553		900		670,194	

transient fish species which supported regional sport and commercial fisheries. For example, over 1500 juvenile common snook were captured during a single 3-hr culvert trap set in a restored, previously impounded, mangrove wetland, Jack Island State Park, on the barrier island in St. Lucie County, Florida. This is the single largest capture of this species as juveniles recorded in Florida waters and demonstrated the value of mangrove habitat for this species and its utilization of a restored tidal connection between the mangrove forest and the estuary. The trophic work of Luczkovich et al. (1995) included this species, verifying the major role mangrove residents play in the diet of predaceous transients in restored mangrove wetlands first demonstrated by Harrington and Harrington (1961, 1982) and Gilmore et al. (1983).

One of the first definitive research efforts in the United States to target early juvenile fish habitat modification as a major limiting factor to adult fishery stock considered of commercial importance was that of Gilmore et al. (1983) documenting the life history of the common snook in the Indian River on the east coast of Florida. This species is a prized game fish that had been primarily managed by closure of its fishery to commercial harvest in 1957, and subsequent recreational harvest limits, neither of which has been shown to maintain or increase the adult stock. Gilmore et al. (1983) determined that while adult common snook spawn in higher salinity coastal passes, the early juvenile snook (mean 27.5 mm standard length, SL) are found in shallow freshwater tributary streams entering estuarine waters and in polyhaline to marine barrier island mangrove forests. Juvenile common snook typically leave peripheral mangrove and freshwater habitats as they reach 100–150 mm SL, moving into seagrass meadows as they mature, at a mean of 240 mm SL. However, larger juvenile and mature adults will periodically visit tidal fringe mangrove forest habitats, rivers and creeks where adequate prey and water depth allow. Important food items for juveniles included fish, shrimp, and microcrustaceans, with the eastern mosquitofish, *Gambusia holbrooki* Girard, 1859, being the dominant identifiable fish species in specimens < 100 mm SL (Gilmore et al., 1983; Luczkovitch et al., 1995).

Along the coasts of central Florida, the role of mangroves and the mangrove-marsh mixture in the production of small forage fish species [eastern mosquitofish; rainwater killifish: *Lucania parva* Baird and Girard, 1855; sailfin molly: *Poecilia latipinna* (Leseur, 1821); sheepshead minnow: *Cyprinodon variegatus* Lacépède, 1803; *Fundulus* spp.; diamond killifish: *Adinia xenica* (Jordan and Gilbert, 1882)] essential as dietary items for larger and more commercially important fishes (as well as wading birds and seabirds) is underappreciated and rarely documented (Fore and Schmidt, 1973; Gilmore et al., 1983; Luczkovitch et al., 1995). The few studies focusing on this function of mangroves and mangrove-marsh communities include Harrington and Harrington (1961), Gilmore et al. (1982, 1983), Rey et al. (1990), Ley et al. (1994), and Whitman and Gilmore (1993). Robertson and Duke (1990) make a similar point about the valuable Australian fishery for barramundi (*Lates calcarifer* Alexander, 1845): “[O]nly a small number of fish species examined in this study are of direct economic importance... (H)owever, the valuable commercial gill net and recreational line fisheries for barramundi... are intimately linked to mangrove habitats... our data... show that more than 50% of the diet of subadult *L. calcarifer* is composed of the small fish which dominate the mangrove habitats...”

In spite of this, the recent review of Manson et al. (2005), in discussing groups of mangrove dependent fish species states “(A) final grouping is the true estuarine species that complete their entire life cycle within estuaries. These species are clearly es-

tuarine-dependent but many are small and short lived...and few contribute directly to fisheries, . . . (and) . . . will not be discussed further. Instead, the focus will be on the marine-estuarine category that includes a number of economically important species." We believe ignoring the role of small mangrove-dependent fish in the families Gobiidae, Atherinidae, Cyprinodontidae, and Poeciliidae, for example, as important mangrove-dependent species is neither an ecologically sound approach to mangrove forest management and restoration, nor estuarine fisheries management.

Gilmore et al. (1983) concluded that, "loss of habitat and general degradation of water quality has undoubtedly had a more permanent and, therefore, far greater effect on reducing snook populations than the fishery. Removal of juvenile habitat curtails recruitment from the largest portion of the snook population and that portion which is most susceptible to natural mortality." Similar life history implications are reported for other key commercial and recreationally important estuarine fish species, such as redfish (*Sciaenops ocellatus* Linnaeus, 1766), spotted seatrout [*Cynoscion nebulosus* (Cuvier, 1830)], and tarpon (Lewis et al., 1985; Lewis, 1990).

Similar restoration is reported by Barimo and Serafy (2003) where fish utilization of a 30 ha mangrove restoration site in Biscayne Bay, Florida, with 28 ponds connected to adjacent waters by a series of tidal creeks, supported 25 fish species 1–3 yrs after restoration. The most common of these species were the gold spotted killifish [*Floridichthys carpio* (Gunther, 1866)]; yellowfin mojarra [*Gerres cineris* (Walbaum, 1792)]; and rainwater killifish. Sampling of ponds of various ages revealed a general trend in increasing fish community diversity over time.

Finally, fragmented or hydrologically restricted or isolated mangrove habitat in the Bahamas has shown reduced numbers of fish species (Layman et al., 2004) similar to the data of Harrington and Harrington (1961, 1982), Gilmore et al. (1982), and Gilmore (1987a). Community-based hydrologic restoration of these areas led to increases in fish and invertebrate utilization after restoration (Layman and Arrington, 2005). Layman et al. (2004) proposed that hydrologic restrictions influence fish and invertebrate abundance through: (1) reduced tidal exchange producing decreased habitat quality (e.g., greater salinity extremes), (2) reduced tidal exchange lowering the influx of planktonic larvae and juveniles of estuarine dependent species, and (3) non-permeable landscape features (e.g., roads without culverts) halting upstream movement by transient marine species [e.g., bonefish, *Albula vulpes* (Linnaeus, 1758)].

#### IMPROVING THE SUCCESS OF RESTORATION

Great potential exists to reverse the worldwide loss of mangrove forests, and thus enhance fish and invertebrate habitats, through application of basic principles of ecological restoration using ecological engineering approaches. Previously documented attempts to restore mangroves, where successful, have largely concentrated on creation of plantations consisting of a few mangrove species targeted for harvest as wood products or temporarily used to collect eroded soil and raise intertidal areas to elevations usable for terrestrial agriculture [see review by Lewis (2005)]. But many expensive efforts to restore mangroves have failed (deLeon and White, 1999; Erfte-meijer and Lewis, 2000), and most attempts to restore mangroves never even achieve significant cover by mangrove species, or meet their stated goals (Erfte-meijer and Lewis, 2000; Lewis and Streever, 2000; Lewis, 2000, 2005).

We suggest there should be three restoration strategies for fish habitat optimization:



*Strategy 1: Achieve plant cover similar to that in an adjacent relatively undisturbed and mature mangrove ecosystem.*—Due to the length of time it may take to achieve full maturity in a restored mangrove forest (25–50 yrs minimum), the likely actual measurable criterion will be the establishment of a trajectory (based upon regular monitoring of multiple parameters, such as plant cover by species and density and height of mangroves) that, if continued, would establish such mature forest cover [see Lewis et al. (2005) for a typical trajectory curve and successful forest cover establishment at 36 mo post restoration]. Such vegetation development trends are rarely documented or reported, however, in part due to the high failure rate of mangrove restoration.

*Strategy 2: Establish a network of channels that mimics the shape and form of a natural tidal creek system.*—Tidal creeks are important as pathways for the movement of mangrove detritus and for their function in maintaining water quality (particularly with regard to the dissolved oxygen levels required to support fish and invertebrates), as well as for their role as entry points on flood tides and exit points on ebb tides for mobile nekton. Although this seems obvious from a fisheries perspective, mangrove restoration projects are frequently completed without concern for reconnection or construction of tidal creeks. Even when a network of channels is incorporated into the design, it too often consists of just rough-cut ditches dug without consideration of the resulting tidal prism, the desired exchange of tidal waters with adjacent estuarine or oceanic waters, or whether velocities will be high enough to keep the new channels open over time (Turner and Streever, 2002). Instead, channels should be designed to serve natural functions and be as self-maintaining as possible.

*Strategy 3: Establish a heterogeneous landscape similar to that exhibited by the local mangrove ecosystem.*—Mangrove ecosystems include the mangrove forest itself, its associated animal community, and adjacent and hydrologically linked wetlands. Important contiguous plant communities include terrestrial plant communities in the watershed, and shallow marine communities including tidal ponds, tidal flats, seagrass meadows, and coral reefs. The landward portion of the mangrove ecosystem includes salt flats or salinas, as well as freshwater streams and wetlands (both marshes and forested wetlands) that ultimately drain to the sea via both surficial and underground waterways through mangrove forests. The seaward edge of the mangrove ecosystem is the outer edge of the influence of water flows coming from drainage through the mangrove forests and may extend several kilometers offshore. Mangroves have also been ecologically linked with fish movements from adjacent coral reefs and seagrass meadows (Ley and McIvor, 2002; Mumby et al., 2004).

Lewis (2005) reviews the most likely points of failure in successful mangrove forest restoration and offers a simple sequential checklist of design tasks, that, if followed rigorously, would prevent most of these failures. Callaway (2001) recommends seven similar steps be taken in designing for hydrologic and geomorphologic development of tidal marshes in California. Both Vivian-Smith (2001) and Sullivan (2001) suggest addressing these factors through the use of a reference tidal marsh for restoration planning and design, which applies equally well here for mangrove forest restoration.

Five sequential design tasks have been suggested by Stevenson et al. (1999) as essential to implementing the strategies listed above, and successfully restoring mangrove forests. Following these design tasks in sequence will prevent most of the common errors in mangrove forest restoration design.

1. Understand the autecology (individual species ecology) of the mangrove species in the vicinity of the restoration site, paying particular attention to patterns of reproduction, zonation, propagule distribution, and seedling establishment.
2. Understand the normal hydrologic patterns controlling the distribution and successful establishment and growth of the targeted mangrove species.
3. Determine what modifications and stresses of the previous mangrove environment are currently preventing natural secondary succession.
4. Design the restoration program to first reestablish the appropriate hydrology at an appropriate restoration site, and then utilize natural volunteer mangrove propagule recruitment for plant establishment.
5. Only plant propagules or seedlings after determining through steps 1–4 that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization, or rate of growth of saplings set as goals for the restoration project.

The more common alternative approach to mangrove restoration is to first build a nursery to grow mangrove seedlings, then produce large numbers of potted mangroves for planting, and finally identify a location to install the nursery-grown plant materials. This is referred to by Lewis (2005) as the “gardening” approach. Often unvegetated mudflats that have never supported mangroves are chosen for such garden sites, and frequently most or all of the plants installed die in a short time, or remain stunted due to excessive flooding and stress due to extended soil saturation (Erftemeijer and Lewis, 2000). In reality, actual planting of mangroves is rarely needed to establish plant cover unless a site has been identified as “propagule limited” (Lewis, 2005).

Previous research has documented the general principle that mangrove forests worldwide occur on raised and sloped platforms situated above mean sea level and inundated less than thirty percent of the time by tidal waters (Lewis, 2005). More frequent flooding can cause stress and death of these tree species (Turner and Lewis, 1997). Preventing such damage requires a detailed understanding of local mangrove hydrology. Again the inclusion of correctly designed tidal creeks in a mangrove restoration design provides access to this platform on high tides, and refuge within the creeks on low tides if properly designed.

Because degraded mangrove forests may recover without active restoration efforts, restoration projects should begin with a search for hydrologic sources of stress (such as blocked tidal inundation), or roadways within the forest without adequate cross connections both upstream and downstream of the road, that might be preventing secondary succession, then focus on removing that stress (Hamilton and Snedaker, 1984; Cintrón-Molero, 1992; Layman et al., 2004; Layman and Arrington, 2005). Once normal hydrology has been reestablished, the next step is to observe whether natural seedling recruitment occurs. Planting should be considered only if this does not happen.

It is important to understand that mangrove forests occur in a wide variety of hydrologic and climatic conditions that result in a broad array of mangrove community types. In Florida, Lewis et al. (1985) identified at least four variations on the original classic mangrove zonation pattern described by Davis (1940), all of which include a tidal marsh component dominated by such species as smooth cordgrass (*Spartina alterniflora* Loisel.) or saltwort (*Batis maritima* Linnaeus). Lewis (1982a,b) describes the role that smooth cordgrass plays as a “nurse species” that initially colonizes bare soil and facilitates primary or secondary succession to a climax community domi-



nated by mangroves, but with some remnants of the original tidal marsh vegetation typically remaining. Crewz and Lewis (1991) further discuss the tidal marsh component typical of Florida mangrove forests.

The typical "mangrove restoration" project aimed at establishing a monospecific stand of planted *Rhizophora* spp. fails to restore the freshwater-marine salinity gradient and plant biodiversity characteristic of intact mangrove ecosystems. Establishing this salinity gradient and a related variety of habitat types must be the goal of any mangrove restoration project intended to provide fish habitat and enhance biodiversity. Besides providing food and habitat for a broad spectrum of fish, invertebrates, and associated wading birds, seabirds, and other wildlife, incorporating this estuarine gradient maximizes both above- and belowground productivity of mangroves and their ability to deal with rising sea levels (Snedaker, 1993).

### RESTORATION OPPORTUNITIES

There are both large and small opportunities for mangrove restoration. Both have a role in mangrove forest management, but it is important to understand that very small restoration projects, such as the typical shoreline plantings of a few hundred or thousand mangroves are generally neither as cost-effective on a per hectare basis nor as ecologically valuable as larger hydrologic restoration projects, such as restoring normal seasonal freshwater flows to mangroves in Florida Bay (Ley et al., 1994; Ley and McIvor, 2002) or Biscayne Bay (Braun et al., 2004). Large scale hydrologic restoration, such as that described by Brockmeyer et al. (1997), has produced real ecological benefits for US\$250 ha<sup>-1</sup>. Small local citizen-based restorations still have educational value and can play a supplementary role, especially in regard to reestablishing species and community diversity along the urban interface (Layman and Arrington, 2005). But where money is limited and/or fish habitat optimization is the goal, we should listen to the words of Spurgeon (1998): "[I]f coastal habitat rehabilitation/creation is to be widely implemented, greater attempts should be made to: find ways of reducing the overall costs of such initiatives; devise means of increasing the rate at which environmental benefits accrue; and to identify mechanisms for appropriating the environmental benefits." There are many opportunities to restore mangroves worldwide, including at least several hundred thousand hectares of abandoned shrimp aquaculture ponds, primarily in Southeast Asia, but also in Ecuador and Brazil (Stevenson et al., 1999).

### CASE STUDY

Aerial photographs of the same mangrove restoration site over a period of 4 yrs represent a portion of a 500 ha hydrologic restoration project at West Lake (WL) in Hollywood, Florida (Fig. 1; described in Lewis (1990)). Success resulted from using a reference site, and targeting final constructed grades to be the same as the adjacent undisturbed forest. This resulted in a final sloped grade from +27 cm to +42 cm mean sea level (MSL). Extensive constructed tidal creeks and shallow mudflats were also added to the original plans which had been designed and originally permitted without them. No planting of mangroves took place or was necessary. All three of the Florida species of mangroves (red mangrove *Rhizophora mangle* Linnaeus, black mangrove *Avicennia germinans* (Linnaeus) Linnaeus, and white mangrove *La-*

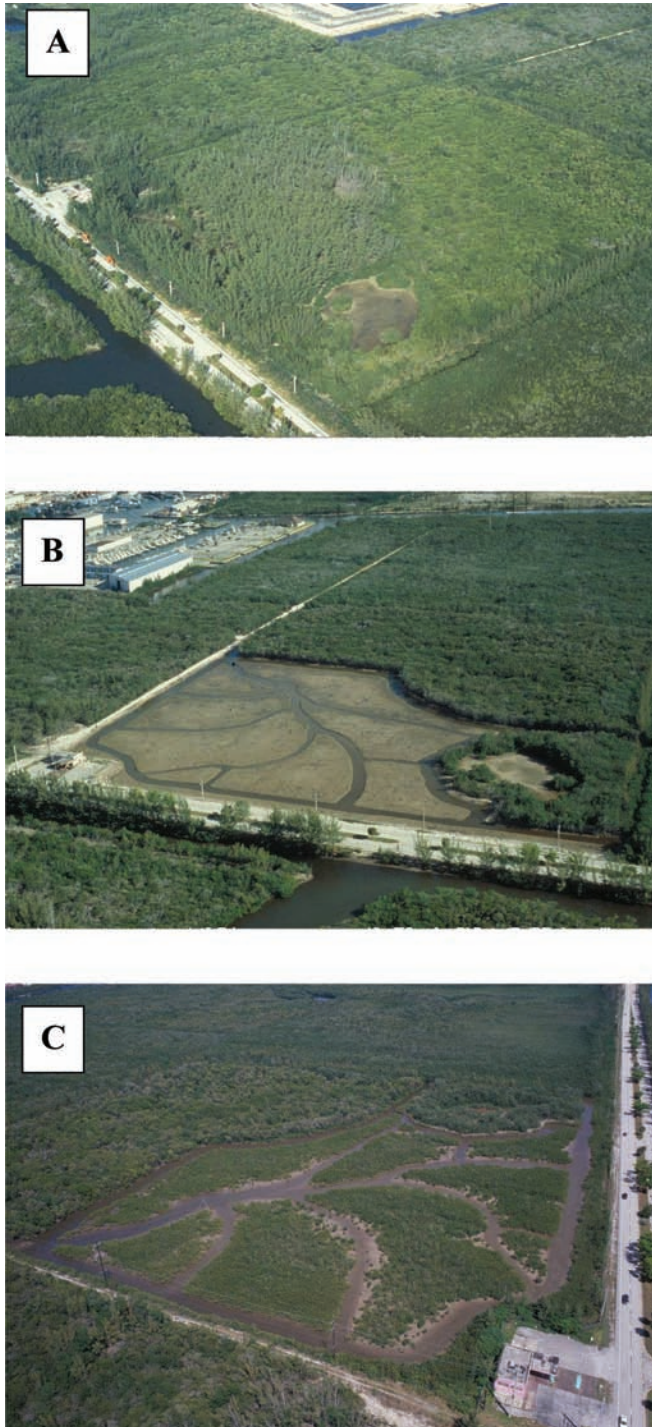


Figure 1. Oblique aerial photographs of a portion of the hydrologic mangrove restoration project at West Lake Park, Hollywood, Florida over three time periods: (A) Preconstruction, July 1987, (B) completion of construction, August 1989, and (C) 2 yrs post-construction, May 1991. No planting of mangroves occurred. All vegetation derived from volunteer mangrove propagules.

*guncularia racemosa* (Linnaeus) Gaertn.f.) volunteered on their own. High marshes dominated by *B. maritima* were also hydrologically restored. This type of major excavation to restore mangrove habitat is similar to the successful efforts reported by Barimo and Serafy (2003) for Biscayne Bay. Another form of hydrologic restoration is to reconnect impounded mangroves to normal tidal influence (Brockmeyer et al., 1997; Turner and Lewis, 1997; Layman and Arrington, 2005).

Comparative sampling of fish populations within both restored and natural reference areas at WL, and adjacent natural and restored sites at John U. Lloyd Park (JUL; Roberts, 1994), resulted in the collection of 9937 fishes representing 34 species in the JUL reference sites, 6835 fishes representing 28 species at the JUL mangrove restoration sites, 9141 fishes representing 36 species at the WL reference sites, and 11,374 fishes representing 31 species from the WL restoration site. The predominant species were bay anchovy *Anchoa mitchilli* Valenciennes, 1848; juvenile mullet *Mugil* spp.; yellowfin mojarra *Gerres cinereus* (Walbaum, 1792); silver jenny *Eucinostomus gula* (Quoy and Gaimard, 1824); striped mojarra *Eugerres plumie* (Cuvier, 1830); eastern gambusia; sailfin molly; marsh killifish *Fundulus confluentus* Goode and Bean; 1879, and goldspotted killifish. Statistical tests of the differences in fish assemblages, and total mean abundance in the natural and 3–5 yr old restored mangroves sites were not significant. Lewis (1992) noted in reviewing similar reports on fish use of tidal marsh restoration sites in Florida, North Carolina, and California that "...rapid (3–5 yrs) establishment of comparable fish communities in created and restored coastal wetlands, when compared with natural wetlands, is a generally documented observation..."

## CONCLUSIONS

Ellison (2000) asks the question "mangrove restoration: do we know enough?" His answer is that "[R]estoration of mangal does not appear to be especially difficult..." and comments that in contrast to the complexity of restoring inland wetlands, "...it is more straightforward to restore tidal fluctuations and flushing to impounded coastal systems where mangroves could subsequently flourish..." Thus, ecological restoration of mangrove forests is feasible, has been done on a large scale in various parts of the world, and can be done cost-effectively. Fish utilization of these restored ecosystems has, however, not been a routine measure of successful restoration, and we recommend more use of this criterion in the future.

Lewis (2005) recommends that an ecological engineering approach be applied to mangrove ecosystem restoration projects. The simple application of the five steps outlined by Stevenson et al. (1999) would at least insure an analytical thought process and minimize resources wasted on futile mangrove "gardening" efforts. To optimize fish use of restored mangrove ecosystems, we recommend planning restoration projects around the three key strategies outlined earlier: establishing plant cover, a network of tidal channels, and a landscape mosaic, all of which mimic natural undisturbed systems and reflect the zonation and diversity of the local mangrove ecosystem, including freshwater inputs to the landward edge of a normal estuarine gradient.

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