Evaluating the Effects of Restoration on Estuarine Fishes

Project Report to
Southwest Florida Water Management District
Project Period: October 1 2006 – September 30, 2007
Report Date: December 2007

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Mote Marine Laboratory Technical Report No. 1509
Introduction

Florida’s southwest coastline has been drastically altered for development, water management, agriculture, mining, and mosquito control purposes (references cited in Lin and Beal, 1995; Poulakis et al., 2002). Historically, during the rainy season, water would inundate vast stretches of upland habitats (wet and mesic pine flatwoods, hydric hammocks, and coastal tropical hammocks) and drain as slow, overland sheetflow to oligohaline and mesohaline marshes at the upper reaches of the tidal estuarine system. In areas with larger drainage basins, surficial flows were concentrated into tidal creek systems, creating a permanent flow corridor between upland salt ponds and tidal marshes. During the dry season, wet prairies and hydric hammocks dry-out, seasonally removing the corridor between upland salt ponds and tidal marshes. In larger drainage systems, tidal creeks remained connected to the upland saltwater ponds.

Anthropogenic alterations of freshwater flows into estuaries are of particular concern to resource managers because such changes impact estuarine ecology (Sklar and Browder, 1998; reviewed in Beach 2002). Freshwater flow is a major ecological structuring factor in estuaries, influencing abundance and distributions of vegetation, and of invertebrates and vertebrates that use estuaries for some or all of their life cycles. The increase in impervious surfaces and loss of wetland habitats associated with coastal development alter the source, timing, and velocity of freshwater flows, which influences salinity patterns (Sklar and Browder 1998). Whereas some organisms can tolerate wide ranges in salinity, most species have narrow salinity tolerances or migrate to remain in a preferred salinity range (Montague and Ley 1993, Sklar and Browder 1998), thus altering habitat use patterns. When > 10% of a watershed’s acreage is converted to impervious surface, the water bodies become seriously degraded, and are less diverse, productive, and stable (reviewed in Beach 2002). Lower organism abundances, lower
recruitment, and shifts in dominant species often result from high pulses in freshwater runoff (Sklar and Browder 1998, reviewed in Beach 2002, Beever and Chamberlain 2002, Wyda et al. 2002). With 25% of United States coastal habitats expected to be developed by 2025 (14% of coastal habitats had been developed by 2002) (Beach 2002), there is an exigent need to understand how habitat alterations impact fishes so that appropriate conservation and management measures can be enacted. This is especially true in Florida, with one of the fastest growing populations in the United States.

Relative to many other estuaries Charlotte Harbor habitats remain in good condition – much of the mangrove shoreline is intact and government owned, and seagrass coverage has not changed significantly in ten years of monitoring. Increasingly rapid coastal development, however, threatens to alter the estuary’s watershed, thus altering freshwater flow into the estuary. In fact, habitat-associated effects of such alterations are becoming evident in some locations. This combination of unaltered and altered habitats makes Charlotte Harbor a perfect location for studying the effects of habitat alteration on fish-habitat interactions, and formulating management strategies to conserve estuarine habitats.

Research to determine the effects of upland development and subsequent alterations of freshwater flow, and of restoration of coastal habitats to restore natural flows, on estuarine fishes is urgently needed. This is true at the fish assemblage level (which species are most or least impacted by flow alterations), as well as for juvenile life stages of economically important species, such as common snook, *Centropomus undecimalis*, that comprise the saltwater recreational fishery that generates approximately $5.4 billion annually in Florida. Restoration has been seen as an effective means to repair anthropogenic ecological damage, but quality data on the impacts of upland restoration on estuarine ecology are rare. The assumption that restoration of natural freshwater flows will have positive ecological impacts has rarely been
This is because, in most cases, there are insufficient pre- and post-restoration data to allow a conclusion on the restorations effects.

This report summarizes sampling in mangrove creeks of Charlotte Harbor that occurred between October 2006 and September 2007. The sampling funded by SWFWMD occurred in two mangrove creeks in the Charlotte Harbor Preserve State Park, in Charlotte County. The uplands of these creeks are undergoing restoration, and sampling was conducted to determine the extent that the restoration process influences fish assemblages in the mangrove creeks. As a means of comparison with creeks with uplands that are undergoing development, parallel sampling was conducted in two mangrove creeks just south of the Lee-Charlotte County line, with these creeks serving as a standard for degraded, non-restored creeks. In addition, this project summary includes data from more than three years prior to upland restoration in Charlotte Harbor Preserve State Park. This temporal and spatial comparative approach is essential to determining the effectiveness of upland habitat restoration to improving mangrove creek habitat quality.

Methods

Study Location

Charlotte Harbor is a 700 km² coastal plain estuarine system in southwest Florida (Hammett 1990) (Figure 1). The Peace, Myakka, and Caloosahatchee rivers, as well as many smaller creeks throughout the drainage, transport large amounts of the fresh water into the harbor. The harbor is connected to the Gulf of Mexico through Boca Grande Pass, San Carlos Bay, and three smaller inlets. The climate of Charlotte Harbor is subtropical; mean seasonal water temperatures range from 12° to 36° C, and freezes are infrequent. Anthropogenic development within the watershed has stressed the estuarine system; however, compared with many other estuaries (e.g.,
Chesapeake Bay, Tampa Bay), Charlotte Harbor has remained relatively unspoiled (> 80% of mainland shorelines under protection; R. Repenning, Florida Department of Environmental Protection, pers. comm.; Hammett 1990). Seagrass flats (262 km²; Sargent et al. 1995) and mangrove shorelines (143 km²; L. Kish, Florida Fish and Wildlife Research Institute, unpubl. data) continue to thrive as the dominant habitats within the estuary. Despite coastal habitat protections, however, upland habitat degradation has caused considerable alterations of freshwater flow into estuarine habitats, particularly mangrove creeks that provide essential habitat for many fish species. Restoration of upland habitats to restore natural freshwater flows was recently initiated. Data generated from this project allowed a first examination of the effectiveness of this upland restoration at improving habitat quality of mangrove creeks.

Established Database

Sampling of fishes in four mangrove creeks along the eastern shoreline of Charlotte Harbor has been ongoing since February 2003. The two creeks south of the Charlotte-Lee County line are considered very degraded, such that their drainages and wetlands have been altered for development, creating impervious surfaces and altering freshwater flow regimes. The altered flow regimes cause short, pulsing hydroperiods limited to the immediate creek with little overland sheet flow. The bottoms are mostly hard sand, and the submerged aquatic vegetation (Ruppia maritima and Halodule wrightii) is patchy and limited to the lower two-thirds of the creeks. The creeks are narrow (mean = 5 m) for the upper two-thirds, and have wider bays (60 m) only in their extreme lower portions. Narrow sections are scoured to > 2 m depth with undercut banks, and greatly reduced width of the intertidal mangrove prop root habitat.

In contrast, the two creeks that were the focus of this project and are located within the
Charlotte Harbor Preserve State Park, are considered less degraded, such that their morphology remains largely intact, but their upland drainages have been crisscrossed with mosquito ditches and earthen berms, which have altered freshwater flows into the creeks. Creek widths range from 2 m in narrow passes to >60 m in wider bays, depth is shallow (< 0.5 m except in narrow passes where depths reach 1m), shorelines are lined entirely by red mangroves *Rhizophora mangle*, and bottom is mixed mud and sand. The submerged aquatic vegetation in the upper stratum is entirely *R. maritima*, whereas the middle and lower strata are dominated by *H. wrightii*.

The sampling from 2003 through 2006 has provided a baseline of data which was essential to the success of this project. These baselines were used as temporal benchmarks for comparison with data from this project, collected while restoration was ongoing. Sampling in the two southern degraded creeks provided a spatial standard for comparison.

*Sampling Design*

Each creek was divided into three equal strata (upper, middle, lower) for sampling, with five samples per stratum, and thus 15 samples per creek, per sample period (Figure 1). Fishes were sampled with a 21m x 2m center bag seine with 3.1mm mesh. For each sample, the net was set in a semi-circle against a mangrove shoreline and pursed to force fish into the bag, all fish identified to the lowest taxon possible, the first 25 individuals of each taxon measured (standard length) and the remainder counted, and temperature, salinity, and dissolved oxygen recorded with a handheld YSI 556 MPS. For water depth >0.25m, abiotic data were collected from the water surface and bottom, and for water depth ≤0.25 abiotic data were collected from mid-water. All fish were returned to the water at the site of capture.
Sampling occurred every other month, beginning in October 2006. Sampling effort was focused near times of low tide to maximize sampling efficiency: at low water levels, fishes were forced out of the mangrove prop-roots and collect along exposed shorelines, making them more susceptible to capture by seine. Sampling in all creeks occurred within a two week period within each sample month.

Data Analysis

Abiotic data were pooled by creek and zone, and a paired t-test was used to determine whether these variables differed between surface and bottom. Salinity required a square-square root transformation to approximate normality prior to analysis. Dissolved oxygen and water temperature did not require a transformation. Abiotic variable means and standard errors were calculated by creek and zone for each sample period, and examined graphically.

Fish taxa were defined as residents (R), transients (T), juveniles (J), freshwater (F), or exotics (E) based upon frequency of occurrence, habitat requirements, dominant life stage when in the creeks, and whether they were native to the region (Robins et al. 1986, Page and Burr 1992, Shafland 1996, http://www.floridafisheries.com/fishes/exotic%20List.html). Residents were present in > 35% of samples and have creek-associated habitat requirements, transients were marine or estuarine species able to use numerous habitats and present in < 36% samples, taxa were categorized as juveniles when > 90% of individuals captured were juveniles, freshwater taxa were obligate residents of fresh or oligohaline waters, and exotics were non-native species as defined by Shafland (1996). Total abundance of each species was calculated for each creek for samples from 2003 through 2007 to show overall creek fish assemblage structure, and ranked in order of total abundance.
To determine among-creek and among-zone patterns of occurrence for the five most abundant resident species and juveniles of the economically important common snook during the study period, densities were examined with a three-way ANOVA for each species, with creek, zone, and sample period as factors. Size frequency distributions of these species were also examined by creek and zone.

Mean density (no. fish/m²) and frequency of occurrence (total number of samples in which the taxon occurred) were calculated by creek for each taxon for the study period, and examined with cluster analysis (standardized, Average linkage method, Euclidean distance) to determine the extent of (dis)similarity among fish assemblages in the different creeks (Wilkinson et al. 1996). The cluster analysis results were compared to cluster analysis results from prior to the study period.

Total abundance and species richness data were calculated for each creek for the study period, combined with data collected prior to the study period, and examined graphically for trends.

Patterns of occurrence for the most abundant non-native species, *Cichlasoma urophthalmus* were examined, and are summarized in appendix A.

**Results**

Although SWFWMD funding was used to sample North and South Silcox creeks, results are also reported for Culvert Creek and Yucca Pen to place the Silcox creeks results in a broader context, and show where the Silcox creeks rest along a degradation gradient.

Dissolved oxygen was significantly different between surface and bottom strata in all creeks and zones (Table 1), indicating vertical stratification. The general trend within zones was
for lower DO levels in the southern creeks with degraded uplands and altered freshwater flows. Within creeks, the trend was for lowest DO levels in upper zones. Although there was also vertical stratification of salinity, this was not significant in all creek zones. In general, stratification appeared to be greatest in middle and upper zones, probably because mixing increased with distance downstream. Surface and bottom temperature differed significantly only in Yucca Pen Middle zone. Mean DO, temperature, and salinity for each sample period are shown in figures 2, 3, and 4. Overall, salinity was higher during the study period than during previous sampling because of the lack of regional rainfall. When North and South Silcox Upper zones were compared, salinity was generally lower in North Silcox, especially during wet season, indicating that North Silcox receives more freshwater flow. When Upper zones are compared among creeks, Yucca Pen (which receives a high amount of freshwater flow) had consistently lower salinity than the other creeks. Culvert Creek, with freshwater flow primarily through a raised culvert, showed the most extreme Upper zone salinity fluctuations, and often had the highest salinity among creeks. Water temperature reflected expected seasonal changes, and within sample periods was generally highest in North and South Silcox creeks.

Seine sampling captured 87 taxa among the four creeks: 66 taxa in North Silcox, 62 in South Silcox; 64 in Culvert Creek; and 64 in Yucca Pen (Table 2). Total abundance was highest in South Silcox, followed by North Silcox. Total abundance in Culvert Creek and Yucca Pen was considerably lower. With the exception of Anchoa spp. the ten most abundant species in each creek were similar.

Cluster analysis of frequency of occurrence and standardized abundance revealed differences between the less degraded North and South Silcox creeks and the more degraded Culvert Creek and Yucca Pen. This was true when pre-hurricane Charley data were analyzed
(Figure 5), and when only data from the study period were analyzed (Figure 6), despite the fact that most species densities remained depressed in North and South Silcox creeks after hurricane Charley.

Three of the most abundant resident species (*Gambusia holbrooki, Lucania parva, Poecilia latipinna*) followed a similar temporal trend in abundance (Figures 7, 8, 9). Prior to hurricane Charley, in August 2004, density of each species was greatest in North and South Silcox creeks, and least in Culvert Creek and Yucca Pen. Since hurricane Charley, however, and continuing through this study period, densities were similar in all creeks (i.e., densities in North and South Silcox creeks remain low). Only recently have *L. parva* densities begun to rebound, whereas *G. holbrooki* densities remain depressed. In contrast, densities of *Eucinostomus harengulus* (a habitat generalist) and *Menidia peninsulae* (a creek resident, but highly mobile) have returned to or above pre-Charley densities, and are abundant in all creeks and zones (Figures 10, 11). Densities of juvenile *Centropomus undecimalis* were highly variable over time but, in general, were lower during the study period than during previous sampling periods, indicating poor recruitment during this study period (Figure 12).

**Discussion**

Presentation of results from the project period as part of a longer time series, and in comparison to two creeks with more degraded uplands, underscores the importance of the larger scale effort necessary to evaluate the effects of upland restoration on mangrove creek fishes. In addition, the time series shows that the effects of hurricane Charley appear to be continuing. This research has provided urgently needed quantitative information on the affect of habitat degradation on fish assemblages associated with mangrove creeks (Culvert Creek and Yucca Pen), which can be
used as one metric for evaluating the effectiveness of the restoration on North and Silcox creeks.

Anthropogenic alterations of freshwater flows into estuaries are of particular concern to resource managers because such changes impact estuarine ecology (Sklar and Browder, 1998; reviewed in Beach 2002). Freshwater flow is a major ecological structuring factor in estuaries, influencing abundance and distributions of vegetation, and of invertebrates and vertebrates that use estuaries for some or all of their life cycles. These effects are apparent in Culvert Creek and Yucca Pen, but are less apparent in North and South Silcox creeks.

During this project period, and during previous sampling, although the overall temporal trends in salinity, temperature, and dissolved oxygen (DO) in the creeks were similar, the degraded creeks experienced the most extreme variation. These extreme variations likely contributed to the lower habitat quality of the degraded creeks. In addition, salinity and DO minima were lowest in the degraded creeks, likely reflective of altered freshwater flow regimes.

The effects of low DO on resident fishes, however, is unclear. Many of the resident species in mangrove creeks have behavioral and physiological adaptations to the low DO conditions present in these habitats (Smith and Able 2003), especially if DO levels are higher during the day, allowing for physiological recovery from low DO period.

However, it is likely that the combined differences in abiotic factors between the highly degraded creeks (Culvert Creek and Yucca Pen) and the study creeks caused the differences in species richness, total fish abundances, and abundances of most species were higher in the natural creeks, thus corroborating previous research elsewhere on the effects of freshwater flow alterations. The lack of submerged aquatic vegetation in the upper and lower zones of the degraded creeks further underscores the effects of freshwater flow alterations, suggesting that restoration of natural freshwater flows is advantageous.
Any effects of restoration-associated changes in freshwater flow to North and South Silcox creeks, however, were not evident during the project period. This was entirely due to the drought conditions during the project period, which confounded estimates of restoration effectiveness. Salinity in North and Silcox creeks was higher during this project period than at any other time. A normal or above normal wet season is needed before evaluation of restoration on North and South Silcox creeks can be completed. These high salinities probably caused the low abundance of *G. holbrooki*, which are most common in oligo- and meso-haline conditions. In contrast, the salinity of Yucca Pen remained low relative to other creeks, indicating a very large watershed for the size of the creek.

Another confounding factor was the apparent continuing effects of hurricane Charley on the fish assemblages of North and South Silcox creeks. In the two weeks following the hurricane, fishes in North and South Silcox were observed engaged in surface aerial respiration, a sign of physiological stress. With DO levels below 1.0ppm for weeks, most of these fishes likely died. This was reflected in extremely low catches during post-hurricane sampling. Since these resident fishes depend upon local reproduction to maintain their population, slow recovery was expected, and was dependent upon any survivors and immigrants. In addition, since hurricane Charley, North and South Silcox creeks lacked submerged aquatic vegetation, and the lack of this habitat reduced fish abundances. Resident killifishes and poeciliids depend on the vegetation for shelter and for laying eggs (their stick eggs adhere to the vegetation). Lack of this habitat has probably hindered population recovery of these resident species. However, even with the hurricane effects, densities of these species remain as high or higher than in Culvert Creek and Yucca Pen, emphasizing the importance of maintaining the health of these creek habitats. The next few years should show whether the upland habitat restoration further enhances North and South Silcox
Habitat alteration often facilitates invasions by non-native species (Ross 1991, Courtenay and Williams 1992), and this appears to be the case in this study. Habitat quality of mangrove creeks, as defined by the extent of alteration in upland drainages, is an important factor in the invasion success of *Cichlasoma urophthalmus* into Charlotte Harbor. It appears that upland habitat alteration (ponds and canals) may provide refuge from low temperatures and predation, thus harboring source populations for individuals to colonize estuarine habitats. The presence of drainage ditches and artificial ponds that retain oligo- and meso-haline water year-round (prior to anthropogenic alteration these areas were dry during the dry season), may provide sources of recruitment into Charlotte Harbor’s estuarine habitats. These findings are described in more detail in the attached article journal. Given study findings, it is anticipated that the filling in of mosquito ditches will reduce the number of exotic species reaching North and Silcox creeks. However, because there was very little freshwater flow into the creeks during the project period, the evaluation of the effectiveness of restoration on inhibiting exotic species entrance into the creeks will have to occur in future years.

Density estimates of juvenile snook using seine captures are too variable to provide a good indication of habitat quality or effectiveness of restoration. However, an ongoing study that is being expanded is using PIT tag technology and remote PIT-tag reading antennae to monitor snook movements and estimate population size. The PIT tag approach, which will continue for at least two years, will be very useful in determining the extent that restoration influences juvenile snook use of the mangrove creeks. A research article describing the PIT tag approach is attached.

Given the increasing populations in many coastal regions, incorporation of anthropogenic impacts should be considered for any appropriately-scaled research or assessments. It is likely
that anthropogenic changes will impact habitat types differently, and thus impact fish life stages differently. If resource managers are going to make predictions about the response of coastal ecosystems to anthropogenic changes, the relative effects of anthropogenic changes on different habitats and their associated fishes must be incorporated into their models.

The ability to evaluate the success of habitat restoration projects is of both local and global significance due to widespread habitat loss and diversion of freshwater, and the associated decline in estuarine health. As human populations in coastal areas continue to increase, demands on freshwater resources and coastal habitats will increasingly alter the quantity, quality, and location of freshwater flow, resulting in further degradation of oligohaline systems that provide habitats vital to estuarine and marine species. Quantification of the relationships between flow regimes and habitat quality of oligohaline habitats is essential to long-term management of these areas because oligohaline marshes provide a vital link between terrestrial and estuarine systems.

The findings of the project period were presented as part of a longer time series, and in comparison to two additional mangrove creeks, to underscore the need for both long-term and comparative data to truly evaluate the effectiveness of restoration. Variability is inherent in any natural system, and only by sampling across time and space will this variability be addressed, and a realistic evaluation of restoration accomplished. Time-series data, for example, showed that North and South Silcox creeks have still not recovered from the effects of hurricane Charley. Moreover, even though fish abundances in North and Silcox creeks remain depressed, they are still on par with Culvert Creek and Yucca Pen, a conclusion not possible without the comparative data.

That the project period occurred during a drought may also explain some of the findings. Salinity was higher in the study creeks than at any time during the previous four years. Many
species, *G. holbrooki* for example, do not do well in the salinities present in the creeks curing the project period (40psu in many instances), which may explain the low abundance of these species. Other species that were usually not present or present in low abundance (e.g., *Anchoa* spp.) may have inhabited the creeks because they preferred the higher salinities.

Given the presence of drought during the study period, the lingering effects of hurricane Charley, and the need for a longer post-restoration time series to truly evaluate the effects of restoration, additional years of work sampling are needed.

**Literature Cited**


Mean density of *Poecilia latipinna* by creek and zone. (A) Lower zone; (B) Middle zone; (C) Upper zone. Standard errors omitted to increase clarity of graphs.

Mean density of *Eucinostomus harengulus* by creek and zone. (A) Lower zone; (B) Middle zone; (C) Upper zone. Standard errors omitted to increase clarity of graphs.

Mean density of *Menida peninsulae* by creek and zone. (A) Lower zone; (B) Middle zone; (C) Upper zone. Standard errors omitted to increase clarity of graphs.

Mean density of *Centropomus undecimalis* by creek and zone. (A) Lower zone; (B) Middle zone; (C) Upper zone. Standard errors omitted to increase clarity of graphs.
Table 1. Summary of surface and bottom dissolved oxygen, temperature, and salinity by creek and zone. Variables examined with paired t-test for each creek-zone (salinity was square-root transformed, dissolved oxygen and temperature were not transformed). Data pooled across sample periods (2003 through 2007). See Figure 1 for creek locations and zone designations. Values are non-transformed mean (standard error).

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<tr>
<th>Creek</th>
<th>Zone</th>
<th>Dissolved Oxygen</th>
<th>Temperature</th>
<th>Salinity</th>
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<tr>
<td></td>
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<td>Surface  Bottom</td>
<td>Surface</td>
<td>Bottom</td>
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<tr>
<td>North Silcox\textsuperscript{a}</td>
<td>Lower</td>
<td>3.47 (0.16) 3.18 (0.16)</td>
<td>24.59 (0.49) 28.37 (2.61)</td>
<td>21.65 (1.16) 20.92 (1.44)</td>
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<td>Middle</td>
<td>3.2 (0.2) 2.74 (0.21)</td>
<td>25.48 (0.38) 25.5 (0.41)</td>
<td>18.83 (1.81) 19.42 (1.31)</td>
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<td>Upper</td>
<td>2.11 (0.17) 1.93 (0.2)</td>
<td>25.21 (0.37) 25.69 (0.38)</td>
<td>18.5 (1.02) 18.89 (1.22)</td>
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<tr>
<td>South Silcox\textsuperscript{a}</td>
<td>Lower</td>
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<td>Culvert Creek\textsuperscript{b}</td>
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<td>Yucca Pen\textsuperscript{b}</td>
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\textsuperscript{a} Creeks within Charlotte Harbor Preserve State Park, uplands being restored

\textsuperscript{b} Creeks with altered upland drainages, south of SWFWMD region

\ *= p<0.05; ** = p<0.01; *** = p<0.001