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Mangrove Shoreline Fish Assemblages of Oleta River State Park: Baseline Conditions in an Urban System

Jacquelyn Alexis De Angelo
University of Miami, jdeangelo@rsmas.miami.edu

UNIVERSITY OF MIAMI

MANGROVE SHORELINE FISH ASSEMBLAGES OF OLETA RIVER STATE PARK: BASELINE CONDITIONS IN AN URBAN SYSTEM

BY

Jacquelyn A. De Angelo

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Jacquelyn A. De Angelo

Approved:

____
Daniel O. Suman, Ph.D.
Professor of Marine Affairs
& Policy

____
Terri A. Scandura, Ph.D.
Dean of the Graduate School

____
Joseph E. Serafy, Ph.D.
Research Professor of Marine Biology
& Fisheries

____
Maria L. Estevanez
Professor of Marine Affairs
& Policy

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Oleta River State Park (ORSP), located in North Miami-Dade County is known as the most highly urbanized State Park in all of Florida. The present study was conducted as part of an ongoing seasonally-resolved survey of fish utilization of the mangrove shorelines of Biscayne Bay. Previous Unit Management Plans published by the Division of Recreation and Parks have lacked information concerning the park's prominent mangrove forests along with its icthyofauna. The main purpose of this thesis was to provide a baseline characterization of the mangrove-fish assemblages and microhabitat trends of ORSP, against which future changes in and around the Park can be gauged. Fish assemblages inhabiting the mangrove shorelines were examined using a visual "belt-transect" census method over 11 consecutive seasons. Microhabitat variables including salinity, water temperature, water depth, water clarity and distance from Baker's Haulover Inlet were examined for possible correlations with fish metrics. Several significant differences were evident in the taxonomic richness (number of taxa per unit area) and densities of the five most abundant taxa within the shoreline habitats in terms of seasonal variation and microhabitat variable distribution along the river. Taxonomic richness was typically greater in survey sites located closer to Baker's Haulover Inlet. Oleta River's mangrove shoreline fish assemblages appear to reflect (1) proximity of the mangroves

that they occupy to Baker's Haulover Inlet; (2) temperature regime along the shoreline; and (3) the salinity gradient found within the river. Fish assemblage and microhabitat information collected here could serve as a 'baseline' in future investigations of the effects of further urbanization or the effects of other anthropogenic changes to Oleta River and its mangrove habitat, including possible changes to freshwater flow associated with the Comprehensive Everglades Restoration Plan.

To my family and friends for their love and support
...and to Dr. Elizabeth Irlandi-Hyatt for her wise advice and inspirational strength.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

BACKGROUND

Coastal regions around the world have long served as prime real estate for the phenomena of rapid urban sprawl. In the U.S., the greatest degree of urbanization has occurred in coastal areas of the Atlantic and Gulf of Mexico. The term "urban ecosystem" refers to a geographical region combining urban and natural areas and may also refer to the transformation of areas through urban development (Lee *et al*., 2006). Although the world has become increasingly urbanized over time, humanity continues to depend on natural resources and the various benefits that natural green spaces provide. Many cities are dependent on the ecosystems beyond the city limits, but can also benefit from more internal urban ecosystems (Bolund and Hunhammar, 1999).

A number of detrimental effects to wetlands are linked to the process of increased urbanization. These potential negative impacts to wetland hydrology include such changes in water quality as increased turbidity, nutrients, metals, organic pollutants and decreased oxygen concentration (Ehrenfeld, 2000). Habitat destruction and environmental changes associated with coastal development have the potential to lead to major, long-term threats to biodiversity. In addition to reshaping land and waterways in the process of urban development, many activities associated with urbanization are thought to impact coastal wetlands by altering their once natural states (Faulkner, 2004). Building and development often lead to poor land use practices including release of excess sediments, nutrients, sewage, and toxic materials into coastal waters. Biodiversity is further threatened in highly urbanized areas by oil and gas extraction activities, frequent vessel traffic, and various destructive practices (Bohnsack and Ault, 1996).

While the concept of urbanized communities being constructed near or within natural settings may have mostly negative connotations, there is indication of numerous benefits ensue human populations by being located near urban nature. The term "ecosystem services" can be defined as the benefits human populations derive, directly or indirectly from ecosystem functions (Costanza *et al*., 1997). This concept maintains that environments, such as coastal wetlands, deliver beneficial ecosystem services (e.g., supporting fishery production), as a complement of habitats rather than in isolation. Within an urbanized setting, natural areas have been thought to contribute a number of ecosystem services including filtering of air and water pollution, noise reduction, as well as providing rainwater drainage and added water treatment.

Coastal wetlands also provide significant non-consumptive services, such as tourism and conservation of biodiversity resources, but the value of these services is often difficult to quantify. Natural elements (i.e., trees and bodies of water) in urban contexts contribute to quality of life in a variety of ways. Urban parks and open green spaces can be of strategic importance for the quality of human life of an increasingly urbanized society. Urban nature offers the opportunity for citizens of highly urbanized communities to escape the stress of everyday life, as well as the "oppressive" contours of a city setting (Chiesura, 2004). Numerous studies have shown that the experience of visiting a natural park may reduce stress, enhance contemplativeness, rejuvenate the city dweller, and provide a sense of peacefulness and tranquility (Ulrich, 1981 and Kaplan, 1983).

More specifically, one emerging concept is that coastal wetlands deliver beneficial ecosystem services, such as supporting fishery production, as a complement of habitats rather than in isolation (Lee, 2004). Evidence has shown that when situated near highly urbanized areas, as opposed to more isolated areas, green areas including parks and waterways are utilized more often in ways that benefit the ecosystem (e.g. park cleanup, removal of invasive species) as well as the economy (e.g. revenue to park or green space from charging admission). Assessing the biological and economic mutual benefits that an urbanized ecosystem provides for the surrounding developed area could have strong implications for conservation and management. Currently, most efforts towards sustainability and regeneration focus on man-made and built components of the urban environment. Relatively little attention has been placed on natural components, and management of green spaces near and within urban areas is still deficient. The disregard for green spaces in urban settings is further reflected in damaging reductions in maintenance budgets in towns across the United States. Further evidence of this belief could provide strong support for the development of conservation and management strategies. It is crucial to protect water quality and habitat from potentially destructive human activities which might prevent future generations from enjoying the many benefits which urbanized ecosystems have to offer.

Ecosystems located near highly urbanized cities contribute to urban well-being but may also create adverse effects. This escalation in the amount of human activity in coastal regions has proven to lead to substantial increase in the loss of mangrove habitats, and the wide variety of organisms that depend on them (Duarte *et al*., 2009). Along with the development of land close to existing wetlands comes fragmentation of habitats and harsh impacts on fauna that rely on these ecosystems for shelter, food and reproduction (Schiller and Horn, 1997). Maintaining a high diversity of both plants and animals in a city setting requires that connections between the ecosystems surrounding the city and the green spaces in the city are not significantly disrupted. Due to constant development and expansion of cities in coastal areas, this ideal scenario is rare to find. Activities associated with urbanization are likely to impact coastal wetlands by altering their hydrological regimes, water quality and as a result, regular wildlife assemblages. The mangrove forests lining the shores of Biscayne Bay in Miami-Dade County, one of the country's most heavily populated counties (US Census Bureau), are no exception.

SITE HISTORY AND DESCRIPTION

Oleta River State Park (ORSP), located in North Miami-Dade County is known as the most highly urbanized State Park in all of Florida. Established on March 13, 1980, the ORSP has attracted numerous visitors over the years. The park, which encompasses 1,032.84 acres, has served as a popular destination for biking, picnicking, camping, and fishing for over three decades. Although the Park may be relatively young, Oleta River has a rich history, playing a central and unique role as part of Biscayne Bay's aquatic preserve. The river is especially unique in that it is one of the few remaining riverine mangrove forests in north Miami-Dade County.

Being the largest urban park in the state in a highly developed area, ORSP has tremendous potential for providing recreational opportunities. At the same time, there has been a great need and desire voiced by the public for habitat restoration particularly, because many of its communities were obliterated by dredge and fill activities. Park management must balance these two goals so that recreational land use complements community restoration. A study by Dade County Parks indicated a local demand for fishing, biking and walking (ORSP Unit Management Plan, 2008). Restoration of these natural habitats could serve to create more opportunities for these relatively non-destructive recreational activities.

Although the ORSP includes a designated mangrove preserve, it is not contiguous with the entire park. The mangrove shoreline is situated adjacent to Biscayne Bay west of the lagoon and Florida International University and borders the municipal landfill. The forest canopy lining the coast of Oleta River has been dominated by tall red mangroves (*Rhizophora mangle*) 25 to 50 feet high with black mangroves up to 60 feet in height. The understory consists of a minor amount of red, white and black mangrove seedlings. Over time, boat wakes have caused a moderate amount of toppling of red mangroves in the area. Within the park is an intricate network of channels which provides connectivity throughout the area. Tidal connections between the bay and the preserve are provided by two ditches. A dike along the north and west perimeter of the forest provides some separation between the preserve and the Municipal landfill.

The original topographical conditions of the site have undergone extensive changes over time. Before 1925, the area contained a wide band of mangroves bordering Biscayne Bay, backed by a fresh water marl prairie (Harlem, 1979). Three small freshwater ponds, 0.5 to 2.0 feet deep, were located in the marsh. Less than one acre of the park was above the intertidal zone. Uplands consisted of small hammock islands within the wetlands. In 1935 and 1936, numerous mosquito ditches, one to two feet deep were dug throughout the mangroves. From 1962 to 1964 approximately half of the area that is now the state park was dredged and filled for the Interama project, creating uplands south of the Oleta River and an open water lagoon and canals at the extreme south end of the park. The ponds were filled, although a small remnant of one remains. Average elevation of the filled uplands is approximately + 5 ft above mean sea level. The undeveloped uplands of the park are presently dominated by exotic vegetation (i.e. Australian-pine, Burma reed, etc.) and composed of fill material of various sizes, shapes, and heights. Some are as high as 20 feet. There are also several long narrow canals located throughout the park. Some of these are connected to the open water of the lagoon while others are isolated and non-circulating. These canals are 10 to 20 feet wide and vary in elevation from 0 to -5 feet msl. Elevation of the remaining mangrove forest east of the park road and bordering the Oleta River ranges between 0 and +1 foot msl.

In South Florida, the source of fresh groundwater is the Biscayne Aquifer (Schroeder *et al*., 1958). It is recharged by rainfall primarily during the wet summer seasons. Historically, as water levels increased during the wet season, water flowed east out of the Everglades through natural channels in the Atlantic Coastal Ridge. Near the park, water flowed from the Everglades into Biscayne Bay through the Oleta River, Snake Creek to the northwest and Arch Creek in the South. The wetlands surrounding the park drained into the river through a series of small creeks. In the early 1900s, after Congress passed the Swamp and Overflowed Lands Grant Act, drainage districts were formed and by the late 1920s much of what was once considered wetlands in South Florida, was drained by numerous canals designed to reclaim land. South Florida's wetlands have also suffered secondary impacts from human development pressures.

The alteration of Southeast Florida's hydrology by the elaborate canal systems designed to protect residents from flooding has impacted wetlands by decreasing the water flow necessary for maintaining wetland plant species. Pollutants from storm runoff on streets and highways combined with the use of fertilizers and pesticides have increased the nutrients introduced into surface waters and degraded the water quality that supports wetland plant species. Another negative result of urbanization has been the introduction of non-native plant species or exotics. Melaleuca and Brazilian pepper trees have overgrown wetland areas. Their rapid growth chokes out native species and decreases the habitat value of the wetlands. The implementation of the canal system plus the urbanization of North Miami significantly reduced the overall amount of freshwater runoff into the bay.

One of the most significant modifications to the park occurred in 1925 with the dredging of Baker's Haulover Inlet. The cut was dredged through Miami Beach, connecting North Biscayne Bay and the Atlantic Ocean, increasing saltwater flow into the bay. Before 1925, the Oleta River and North Biscayne Bay were predominantly fresh water systems with a salinity of approximately 4 ppt (ORSP Unit Management Plan, 2008). In 1935 and 1936, extensive mosquito ditches were cut through the wetlands of what is now park property, allowing salt water intrusion further inland. The combination of these hydrological alterations converted Oleta River and the associated wetland communities from a freshwater to a more marine environment, one which is heavily favored by mangroves. In previous documents published by the Department of Environmental Protection, it has been reported that recent salinity conditions in the river vary greatly due to management of the upstream canal by the South Florida Water Management District. In recent years salinity has been documented to fluctuate between 7 and 34 ppt, averaging 25 ppt. Salinity in the surrounding North Biscayne Bay is more consistent, ranging between 26 and 36 ppt and averaging 30 ppt (ORSP Unit Management Plan, 2008).

With the construction of Baker's Haulover Inlet, dynamics in marine life found within the park were altered and change in community structure occurred. The inlet provided a new corridor for a variety of coral reef associated fish taxa to move into and take advantage of the rapidly expanding and highly productive mangrove habitat. According to the most recent management plan, water flow provided by the inlet has benefited the mangrove community by increasing nutrient rich water circulation throughout the area. This implies that Oleta River may potentially serve as a refuge for certain species not common to mangrove estuaries. As the largest urban park in a highly developed area, it has tremendous potential for providing recreational opportunities.

MANAGEMENT OF OLETA RIVER STATE PARK

Numerous organizations play a role in the use and maintenance of Oleta River State Park. These stakeholders include Oleta River park staff, the Florida Department of Environmental Protection, the Florida Fish and Wildlife Conservation Commission, the Miami-Dade County Department of Environmental Resource Management, as well as a number of additional environmental groups and agencies. The Florida Fish and Wildlife Conservation Commission (FFWCC), assists staff in the enforcement of state laws pertaining to wildlife, freshwater fish and other aquatic life existing within park boundaries. In addition, the FFWCC aids the Division with wildlife management programs, including the development and management of Watchable Wildlife programs.

The Department of Environmental Protection (DEP), Office of Coastal and Aquatic Managed Areas (CAMA) aids staff in aquatic preserves management programs. Oleta River State Park, park staff and staff of the Biscayne Bay Aquatic Preserve collaborate on a range of management issues relating to the submerged lands and uplands of the park. Protection of water quality entering the aquatic preserve has been included in recent and ongoing interagency coordination efforts between DEP and local CAMA staff. The DEP, Bureau of Beaches and Wetland Resources aids staff in planning and construction activities seaward of the Coastal Construction Line. The Bureau of Beaches and Wetland Resources aid the staff in the development of coastal erosion control projects. The Miami-Dade County Department of Environmental Resource Management assists the park with restoration of natural communities through mitigation projects and removal of trash from various locations around the park. Regardless of their specific task at hand, for each of these agencies, emphasis is placed on protection of existing resources as well as the promotion of compatible outdoor recreational uses.

Among the most prominent and involved in the use of the park are the citizens and visitors of Miami-Dade County who utilize the park on a daily basis. This includes a number of interest groups including trail bikers, kayakers, beach goers, clean-up volunteers, and perhaps most significant to the park's marine resources, fishers. The public has the opportunity to become further involved by attending public workshops and advisory group meetings conducted by the Division of Recreation and Parks. Prior to the publication of new management plans, open meetings are held to present a draft management plan to the public. In addition, Advisory Group meetings are held to provide Advisory Group members the opportunity to discuss the draft management plan.

In addition to management by the Florida Park Service, the Oleta River and the adjacent area of Biscayne Bay are also managed as part of Biscayne Bay Aquatic Preserve. These waters, as well as all park waters, are classified as Outstanding Florida Waters. Although the designation as Outstanding Florida Water is intended to protect water quality and prevent degradation of the system, the quality of water in the Oleta River and adjacent Biscayne Bay is degraded due to storm water runoff in a densely developed urban area, sewage spills from sewer pipe breaks and leaching of toxic pollutants from marinas and the adjacent Munisport Landfill, a former landfill identified as an EPA Superfund Site.

Every ten years, each Florida State Park, including ORSP, holds a meeting in which the various organizations and interest groups involved in the use and maintenance of the park join to voice concerns and share ideas regarding the park's current operation and status. Based on these problems and suggested solutions, a Unit Management Plan is created. The purpose of the Unit Management Plan is to identify objectives, criteria, and standards which guide each aspect of park administration towards providing resource based recreation, while preserving, interpreting, and restoring natural and cultural resources. More specifically, the plan focuses on two main components of park management. The first is resource management, detailing the inventory and assessment of the park's natural and cultural resources. The management goal of cultural resources is to preserve sites and objects that represent all of Florida's cultural periods as well as significant historic events or persons. This goal may entail active measures to stabilize, reconstruct or restore resources, or to rehabilitate them for appropriate public use. Resource management issues are identified and evaluated, and specific management objectives are established for each resource type. This component of the plan is meant to serve as guidance for the restoration of natural conditions. The second addresses land use, including the formation of a recreational resource allocation plan, based on pre-existing use of the park. Based on considerations such as access, population, and adjacent land uses, an optimum allocation of the physical space of the park is made, locating use areas and proposing types of facilities and volume of use to be provided.

As described by the Unit Management Plan, in the operation and oversight of Oleta River State Park, emphasis is placed on maximizing the recreational potential of the recreation area. However, preservation of resources remains important. Because park units are often components of larger ecosystems, their proper management is often affected by conditions and occurrences beyond park boundaries. For ORSP, ecosystem management is implemented through a resource management evaluation program (to assess resource conditions, evaluate management activities and refine management actions), review of local comprehensive plans and review of permit applications for park/ecosystem impacts. Destruction or depletion of a resource as a result of any recreational activity is not permitted. The philosophy of the Division of Parks and Recreation is natural systems management. Primary emphasis is on restoring and maintaining, to the degree practicable, the natural processes that shape the structure, function and taxonomic composition of Florida's diverse natural communities as they occurred prior to any major anthropogenic changes made over the years. In order to ensure the success of single taxonomic management, natural systems management is first implemented. In an effort to assess the area's recreational potential, development within the park boundaries is aimed at providing facilities that are accessible, convenient and safe, as needed, to support recreational use or park's natural, and educational attributes. Over the years, issues and solutions detailed in previous Unit Management Plans have proven to be effective in restoring and improving various components of ORSP. Since the 2002 approved plan, significant work has been accomplished and progress made in meeting management objectives. According to the 2008 report, accomplishments achieved related to resource management include the restoration of a 4-acre freshwater pond, providing valuable wildlife habitat in the park. It is noted that the park has made significant progress on removing exotic plants and replacing them with appropriate native species. Also completed was a previously proposed restoration project in the northeast section of the park connecting an isolated tract of mangroves with the mangrove community bordering Oleta River.

In addition to featuring achievements made since the previous report, the management plan details park goals and objectives for the future. The park goals and objectives, created and compiled by the Department of Environmental Protection's Division of Recreation and Parks, express long-term interest in managing the park¸ ensuring that goals and objectives for the park remain relevant over time. One of the objectives listed involves providing habitat protection and preservation in order to maintain and increase biodiversity within the park and to protect the flora and fauna that utilize the natural communities of the park. The report further detailed that the park will continue to seek funding to re-vegetate ruderal uplands with native species to create functional maritime hammock communities and increase biodiversity.

Based on goals, objectives and priority management activities, estimates are developed for the funding and staff resources needed to implement each management plan. Visitor fees and charges are the principal source of revenue generated by the park. It is crucial to gain a better understanding of which natural resources within ORSP require protection and regular monitoring in order to more efficiently allocate funds towards preserving the parks ecosystem.

Although the Unit Management Plan designates outdoor recreation and conservation as the two prime objectives of the park, there is a large gap in the information available concerning the park's prominent mangrove forests, along with its ichthyofauna. In the past, few, if any efforts have been made to study, report and preserve local mangrove and fish inhabitants. There is a lack of information concerning both local taxonomic richness (number of fish taxa per unit area) and overall abundance of the local fish community. The most recent Unit Management Plan detailed a series of "Research Needs", which included the recommendation to conduct a survey of submerged communities to determine abundance and location of aquatic species. While the management plan includes species lists of plants, seagrasses, reptiles, birds, amphibians, and mammals, the fish taxonomic list appears to be incomplete. The report also called to attention the necessity for water quality monitoring of surrounding waters and mangrove preserve. There is a large deficit in the amount of available data describing various microhabitat variables, including salinity, dissolved oxygen, temperature, etc., along the river. Because of this lack of knowledge involving the community dynamics of unique reef related fish colonizing the subtropical mangrove habitat found in Oleta River, little has been done to investigate possible actions which could be taken to conserve local fish populations, and prevent further degradation of the mangrove forest. While Oleta River is deemed as a part of Biscayne Bay's "marine preserve", fishing is permitted in most areas of the park in accordance with standards set by the Florida Fish and Wildlife Commission. Without investigating community dynamics of this unique mangrove community, and reporting these findings, resource managers charged with conserving Oleta River's flora and fauna lack a basis for regulating fishing or the continued construction in and around the park, which both could lead to further degradation of this urbanized mangrove forest.

PREVIOUS STUDIES

Numerous studies have suggested that nearshore marine habitats, much like those found in and surrounding Oleta River, could offer an essential habitat for settling post-larvae and developing juveniles (Parrish, 1999). As described by Beck *et al*. (2001), a habitat is considered a nursery for juveniles of a particular taxa if its contribution per unit area to the production of individuals that recruit to adult populations is greater, on average, than production from other habitats in which juveniles occur. Still, critical links are missing to better understand of potential nursery role of subtropical, estuarine mangrove habitats. While a number of studies have proposed the use of marine seagrass beds as fish nurseries, (Gillanders *et al*., 2003), due to a lack of historical data and difficulty in sampling within mangrove prop-roots, large gaps still remain in knowledge of fish assemblages in subtropical estuarine mangrove forests (Halliday and Young, 1996, Serafy *et al.*, 2003). Even less is known about the fish assemblages found in Oleta River State Park. With the addition of Baker's Haulover Inlet to Oleta River came a new corridor connecting the marine environment of the Atlantic Ocean to a more estuarine setting, allowing migration between the two areas. To better manage and monitor fish populations within the park, baseline data are needed.

Based on various baseline reports, some predictions can be made as to what would be found in a subtropical mangrove habitat such as the one examined for the present study. Previous studies have reported a reduction in abundance and diversity with increasing distance from a reef source (Lindeman *et al*., 2000). It has also been suggested that as water becomes less saline, there is a decrease in taxonomic richness, as well as overall abundance, indicating a significant correlation between salinity and abundance and taxonomic richness (Serafy *et al.,* 1997). It could also be predicted that decreases in taxonomic richness and overall abundance of fish found within the river will be observed during the dry season (January to March), with lower water temperatures, rapid changes in salinity, and lower water levels (Sogard *et al*., 1987; Springer and McErlean, 1962). As is shown in Table 1, various studies have focused on the concept of mangroves as significant ecosystems for a variety of fish species and the implications for use of this knowledge towards marine affairs and policy. Few investigations have been conducted in subtropical coastal environments similar to that of Oleta River. There is a great need for future studies that focus on mangrove habitats because they are continuously threatened with continued coastal development. Knowledge of fish populations within state parks is crucial in order to better manage and implement marine resource policy and continuous monitoring efforts.

During the past century, mangroves forests near urban areas have been reduced and fragmented dramatically. This disturbance is believed to be responsible for changes in diversity and abundances of associated marine populations (Clynick and Chapman, 2002). The steady increase in coastal urban development has been known to produce some of the greatest local extinction rates, frequently eliminating a majority of native marine species (McKinney, 2002). As mangrove habitats continue to be modified, degraded or destroyed in the southeastern U.S. and throughout tropical and subtropical ecosystems worldwide (Spalding *et al*., 1997), there is still much to be learned about these rapidly deteriorating subtropical environments and the various fish species which inhabit them. With the implementation of the Comprehensive Everglades Restoration Plan, it is crucial to monitor and understand potential effects that could come along with the alteration of the hydrological regime of Biscayne Bay (Gaff *et al.*, 2000). Loss of both mangrove vegetation and the associated fish populations is difficult to assess with a lack of baseline data. Documentation of habitat usage by fish and the ability to provide accurate assessments of the impact of coastal development on fisheries are critical if areas of potential high fisheries value are to be maintained (Halliday and Young, 1996).

OBJECTIVES

The present study is part of an ongoing seasonally-resolved survey of fish utilization of the mangrove shorelines of Biscayne Bay and adjacent waters. The focus here is on the mangrove-fishes of Oleta River State Park, a semi-natural "oasis" within northern Biscayne Bay, which is highly-urbanized relative to its central and southern portions. The main purpose is to provide a baseline characterization of the mangrove-fish assemblages of ORSP, against which future changes in and around the Park can be gauged. This report will: (1) characterize the mangrove shoreline fish assemblage by means of a taxonomic list; (2) examine seasonal patterns in fish diversity and taxon-specific abundance (fish metrics); and (3) investigate correlations between fish metrics and microhabitat variables. These findings will then be discussed in terms of their utility for Park resource managers and stakeholders interested in maintaining, if not improving, the quality of this urban Park for its many current and future users.

CHAPTER 2: MATERIALS AND METHODS

VISUAL SURVEYS

Surveys conducted throughout this study involve ongoing assessment of taxonomic richness and overall abundance of fish along the Oleta River. Surveys have been conducted during consecutive wet and dry seasons (i.e. July to September and January to March, respectively) beginning in the wet season of 2005 and including four consecutive years of surveys, ending with the dry season of 2010, for a total of 11 seasons. Ten study sites (Fig.1) were chosen in 2005 which span from Baker's Haulover Inlet northwest (upstream) along a 5 km stretch of the Oleta River. Mean distance between sites was about 300 m and these were sampled via visual 'belt-transect' method. The visual 'belt-transect' method was a modification of that described by Rooker and Dennis (1991) and entailed snorkeling a 30 m-long transect parallel to the shore and recording identity, number, and size structure of the fish taxa encountered. Each transect was 2 m wide for a total area of 60 m^2 area examined per transect.

MICROHABITAT VARIABLE ASSESSMENT

Measurements of water quality and depth were obtained at each survey site. Water temperature and salinity were measured using a YSI® multi-probe instrument. Depth was measured along (i.e., at 0, 15 and 30 m) each transect using a 2m-long polyvinyl chloride pole marked off every 1cm. Water clarity was measured with a secchi disk marked in meters. Visual observation was used to characterize the species of mangroves present including red (*Rhizophora mangle*), black (*Avicennia germinans*) and white (*Laguncularia racemosa*).

STATISTICAL ANALYSIS

Once fish and microhabitat data were collected, information was compiled into an Excel spreadsheet along with distance from inlet values. Using statistical procedures in Excel, spatial and temporal variation in fish taxonomic richness and abundance of dominant taxa were assessed. In the event that data displayed problems of non-normality and heterogeneity of variance; they were transferred into rank scores prior to analysis of variance and/or regression. Finally, data were analyzed using multiple regression to reveal the combined influences of the microhabitat variables and distance on taxonomic richness and abundances of the top five fishes. A backwards, stepwise approach was taken whereby the initial independent model terms were temperature, salinity, depth, clarity and distance from inlet. Model terms that emerged as insignificant ($P < 0.10$) were removed and the models were re-run to arrive at final models which best-described fish-habitat-distance relationships.

CHAPTER 3: RESULTS

OVERVIEW

A total of 101, 30 m belt-transects were conducted over 11 consecutive seasons, beginning with the dry season of 2005 and ending with the dry season of 2010. Sample sizes (number of censuses) ranged from 6 to 10 within each season. Thirty-seven fish taxa belonging to 21 families of fishes, were observed (Table 2), 24 in the dry season and 30 in the wet season. The two seasons shared 17 taxa. Taxa unique to the dry season included a snook (*Centropomus undecimalis*), a grunt (*Haemulon flavioneatum*), a mullet (*Mugil cephalus*), a perciform species (*Pseudupeneus maculates*), a goby (*Gobiidae sp.*) and the scrawled cowfish (*Acanthostracion quadricornis*). Unique to the wet season was a group of 30 taxa including two grunts, four parrotfish, needlefish, stingray, searobin, snapper, killifish, mojarra and jack.

Statistical comparisons of fish utilization of Oleta River's mangrove shoreline during dry versus wet seasons and distance from Baker's Haulover Inlet were limited to five variables (Table 3): mean taxonomic richness and mean densities of small, water-column fishes (silversides), small mojarras (*Eucinostomus* sp.), bluestriped grunt (*Haemulon sciurus*), gray snapper (*Lutjanus griseus*) and sailors choice (*H. parra*). Untransformed taxonomic richness values met the assumptions of normality and homogeneity of variance and data were analyzed using analysis of variance (ANOVA) followed by t-tests. Taxon specific density data did not conform to parametric statistical requirements; therefore, these were transformed into ranks.

Ranks were then analyzed with ANOVA – an approach that amounts to the non-parametric Kruskal-Wallis test (Table 4).

MICROHABITAT VARIABLES

As can be viewed in Table 5, significant ($P < 0.01$) seasonal changes in water temperature was evident in all five of the examined years, with mean water temperature being consistently greater during the wet season, ranging from 29.98 to 30.98°C. This varied from water temperature recorded during the dry season, which was significantly lower, ranging from 22.85 to 24.74°C. Salinity, clarity and average water depth all displayed significant ($P < 0.05$) seasonal variation in two out of the five examined years. Clarity was significantly higher during the wet seasons of 2005 and 2007 and salinity was discovered to be significantly higher in the dry seasons of 2008 and 2009. While average water depth was significantly higher in the wet season of 2005, it was discovered to be significantly lower in the wet season of 2009.

Through the use of regression analysis it was determined that both salinity and average depth varied notably with increasing distance from Baker's Haulover Inlet. Salinity decreased significantly ($P < 0.01$) with increasing distance from Baker's Haulover Inlet, ranging from 36.02 ppt at the survey site closest to the inlet to 13.54 at the site furthest from the inlet. Average depth which ranged from 0.00cm to 180.00 cm, decreased significantly ($P < 0.05$) with increasing distance from Baker's Haulover Inlet.

Clarity and temperature were mostly similar at all of the examined sites throughout Oleta River.

TAXONOMIC RICHNESS

Seasonal differences in mean taxonomic richness observed along Oleta River mangrove shoreline habitats were found to be significant in two of the five years examined. As can be seen in Table 3, in 2005 ($P < 0.05$) and 2008 ($P < 0.01$) mean taxonomic richness was significantly lower in the dry season versus the wet season.

Regression analysis indicated that, in general, mean taxonomic richness decreased with increasing distance from Baker's Haulover Inlet in two of the five examined years (Table 4). In the wet seasons of 2007 and 2009, mean taxonomic richness decreased significantly ($P < 0.1$) with increasing distance from the inlet. In only one instance, taxonomic richness increased with increasing distance from Baker's Haulover Inlet.

Multiple regression analysis was utilized to investigate the combined influences of salinity, temperature, salinity, depth clarity and distance of study site from Baker's Haulover Inlet on taxonomic richness. Results indicated that taxonomic richness was significantly ($P < 0.1$) correlated with water temperature, salinity and distance from Baker's Haulover Inlet (Table 4). Taxonomic richness increased with increasing water temperature and salinity levels and decreased with increasing distance from Baker's Haulover Inlet. Upon removal of insignificant ($P > 0.1$) model terms (water clarity and average depth), regression analysis revealed that temperature was the variable most strongly correlated with taxonomic richness (Figure 2).

TOP 5 DOMINANT TAXA

SMALL, WATER-COLUMN FISHES

Mean density of small, water-column fishes was discovered to be significantly higher in the wet season versus the dry season of 2007 and significantly lower in the wet season of 2009 (Table 3). Multiple regression analysis indicated a significant ($P < 0.1$) positive correlation with average water depth (increasing in abundance with increasing water depth) and a negative correlation with distance from the inlet) and a negative correlation with distance from Baker's Haulover Inlet (decreasing in abundance with increasing distance from the inlet) (Figure 3). Average water depth displayed a stronger relationship with mean density than did distance from Baker's Haulover Inlet.

EUCINOSTOMUS SP

Average abundance of small mojarras, *Eucinostomus* sp., observed in Oleta River was significantly ($P < 0.001$) lower in the wet season versus the dry season of 2008 (Table 3). While microhabitat measure correlations were generally weak (Table 4), *Eucinostomus* sp. revealed a significantly ($P < 0.1$) negative correlation with average water depth (Figure 4), indicating that these fishes decreased in abundance with increasing water depth.

BLUESTRIPED GRUNT

While mean density of *H. sciurus* was mostly seasonally similar, average abundance was significantly ($P < 0.001$) higher in the wet season of 2007 (Table 3). Bluestriped grunt was significantly correlated with temperature and water clarity (Table 4). Average abundance of bluestriped grunt displayed a strong significant (P <

0.001), positive correlation with temperature (Figure 5). To a lesser degree, multiple regression analysis also revealed a positive, significant ($P < 0.1$) correlation between average abundance and water clarity, such that *H. sciurus* tended to increase with increasing levels of water quality (Figure5).

GRAY SNAPPER

Mean density of gray snapper, *L. griseus* was significantly ($P < 0.05$) greater in the wet versus the dry seasons of 2006 and 2007, but was statistically similar in 2005, 2008 and 2009 (Table 3). Microhabitat correlations with average abundance were generally weak (Table 4), but mean density displayed a positive, significant ($P < 0.05$) correlation with water temperature, increasing with increasing water temperature (Figure 6).

SAILORS CHOICE

Average abundance of sailors choice *H. parra* was significantly ($P < 0.05$) greater in the wet season versus the dry season of 2007. Seasonal comparisons of mean density were similar for all other years (Table 3). Microhabitat correlations with average abundance of sailors choice were generally weak (Table 4). Mean density showed no significant correlations with salinity, average depth, clarity or distance from Baker's Haulover Inlet but did show a significant ($P < 0.1$), positive correlation with water temperature, increasing with increasing water temperature (Figure 7).

CHAPTER 4: DISCUSSION

OVERVIEW

Results of this study suggest that the mangrove-lined shorelines of Oleta River serve as a highly productive habitat for a variety of commercially significant, reef associated fish species. The list of 37 fish taxa compiled in the present study differs from that of a report published by Serafy *et al*. (2010) which included an 11.5-year visual fish monitoring effort focusing on southern Biscayne Bay. This summary of shoreline fish community visual assessments was the sixth cumulative report in a series of investigations into the potential effects of the Comprehensive Everglades Restoration Plan (CERP) on microhabitat variables and fish assemblages in Biscayne Bay, Florida. Surveys conducted throughout Oleta River revealed 26 of the 57 fish taxa listed by Serafy *et al*. (2010). This discrepancy likely reflects differences in temporal and spatial cope of the sampling efforts made in each of the studies. The present study focused on ten points located within Oleta River over the course of 5.5 years. The Serafy *et al.* (2010) study focused on a relatively larger portion of Biscayne Bay ranging from as far south as Manatee Bay (Barnes Sound) to as far north as Key Biscayne over 11.5 years. The taxonomic list of the present study reports the sightings of numerous reef associated taxa including queen parrotfish (*Scarus vetula*), stoplight parrotfish (*Sparisoma aurofrenatum*), bandtail searobin (*Prionotus ophryas*) and the spotted goatfish (*Pseudupeneus maculatus*), which were not documented in Serafy *et al*. (2010). This observation suggests Oleta River provides habitat for coral reef fishes that is not found south of the Rickenbacker Causeway.

The main quantitative findings of this study were: (1) significant seasonal changes in water temperature were evident in each of the five years examined, with average water temperature being significantly ($P < 0.01$) higher in the warm, wet season. Salinity, water clarity and average depth all displayed significant seasonal variation in two of the five examined years, with water clarity being significantly higher during the wet seasons of 2005 and 2007. Salinity was discovered to be significantly higher in the dry seasons of 2008 and 2009. While average water depth was significantly higher in the wet season of 2005, it was discovered to be significantly lower in the wet season of 2009; (2) Significant seasonal changes in taxonomic richness were detected in two of the five examined years. Of the five taxa examined, all displayed significant seasonal changes in abundance; (3) salinity and average depth varied significantly with increasing distance from Baker's Haulover Inlet, while clarity and temperature remained similar throughout Oleta River; (4) in general, mangrove shorelines of Oleta River harbored greater taxonomic richness and overall abundance at survey sites closer to Baker's Haulover Inlet than those located further inland; (5) survey sites located closer to the inlet contained higher densities of fishes typically associated with coral reef habitats (i.e. grunts and parrotfish) than those further inland; and (6) Taxonomic richness was significantly correlated with temperature, salinity and distance from Baker's Haulover Inlet, increasing with increasing temperature and salinity and decreasing with increasing distance from the inlet. Fish-microhabitat measure correlations were generally weak, but of those examined, temperature was the most influential.

Apart from identifying spatial and seasonal trends, a focus of this study was to determine the extent to which the four microhabitat variables and distance from inlet influences fish taxonomic richness and taxon-specific abundances. As with any field study investigating the influence of several environmental variables on species diversity and abundance, this investigation revealed some confounding among factors, which could lead to misinterpretation of the findings. For example, while it appears that taxonomic richness is most heavily influenced by distance from Baker's Haulover inlet, it is impossible to separate the influences of the salinity or depth gradients that were revealed along the Oleta River. Although laboratory tests could be utilized to further investigate the relationship between abundance and various microhabitat variables, there is no true way to separately investigate the potentially significant roles that individual microhabitat variables might play in influencing taxonomic richness and abundance of the top five taxa. For the purpose of the present study, results of multiple regression tests were used to compare the strength of significant microhabitat variables in shaping taxonomic richness and abundance of the top five most abundant taxa, Based on the P-values of the individual variables, it was determined which was most influential in influencing taxonomic richness and abundances of the examined taxa.

MICROHABITAT VARIABLES

Previous examinations of microhabitat variables within Biscayne Bay have characterized the dry season (January to March) as displaying low water temperature, salinity and mean water levels. The mid-portion of the wet season (July to September) is characterized by higher water temperatures, a transition into higher salinity values and higher mean water levels (Sogard *et al.,* 1987). Similar to these observations, results of the present study displayed significant seasonal changes in temperature in each of the five years examined, with average water temperature being consistently higher in the warm, wet season (July to September). Salinity, water clarity and average depth all displayed significant seasonal variation in only two of the five examined years. Water clarity was significantly higher during the wet seasons of 2005 and 2007 and salinity was discovered to be significantly higher in the dry seasons of 2008 and 2009. While average water depth was significantly higher in the wet season of 2005, it was discovered to be significantly lower in the wet season of 2009.

Salinity and average depth varied significantly with increasing distance from Baker's Haulover Inlet. Both salinity and average depth decreased with increasing distance from Baker's Haulover Inlet. Clarity and temperature remained similar throughout Oleta River. When considering average water depth per transect, results of the present study did share some similarities with a study by Sheridan *et al*. (1992) performed in Rookery Bay, Florida, which assessed an area spanning from an open water marine environment to mangrove-lined shorelines. In this study, analysis of physical characteristics revealed that in the area spanning from an open water marine environment to mangrove-lined shorelines, water depths were consistently greatest in open water habitats and were usually significantly lower in survey sites located nearest to the mangrove habitats (Sheridan *et al*., 1992). Results of the Rookery Bay study did differ from the present study in that no significant differences were detected between salinity levels in open water habitats and those recorded closer to mangrove habitats. Results from an investigation conducted by Singkran and Sudara (2005) revealed that salinity levels monitored in multiple mangrove lined creeks in Trat Bay, Thailand, decreased with increasing distance from open water marine areas, with the lowest water salinity observed at upstream sampling sites.

SEASONALITY

Significant seasonal changes in taxonomic richness were detected in two of the five examined years. The wet seasons of 2005 and 2007 displayed significantly higher taxonomic richness than what was recorded in the dry seasons. Previous studies have also noted that mangrove fish abundance often displays significant seasonality, with the greatest abundance being recorded in the warm, wet-season months of the year (Robertson and Duke, 1991). Seasonal changes in the abundance and composition of tropical and subtropical fish communities have been reported in mangrove systems throughout the world. When compared with these previous studies conducted worldwide, results of the present study are similar in that on a global scale, temperature has been determined to be the most influential determinant of taxonomic richness and the extent of a species range. Laroche *et al*. conducted a study which assessed temporal patterns in fish assemblages in mangrove habitats in a tropical mangrove creek in Madagascar. This particular study reported that taxonomic richness, abundance and biomass were significantly lower in the cooler season. In both Whitewater Bay and areas of Florida Bay, Thayer *et al*. (1987) reported increases in both fish numbers and biomass during the wet season. Significant seasonal differences commonly seen in taxonomic richness and overall abundance is likely to be caused by pronounced environmental fluctuations associated with transitioning from wet to dry seasons (Kupschus and Tremain, 2001). This pattern could further be explored by investigating microhabitat variables (e.g. temperature and salinity) which vary significantly between seasons.

WATER TEMPERATURE

Generally, results of past studies have indicated that seasonal differences in fish assemblage composition and structure are most heavily influenced by contrasts in water temperature (Moyle and Cech, 1998; Hammerschlag and Serafy, 2010). In is believed that in many cases, temperature can be considered the limiting factor in determining a particular taxon's ability to inhabit a certain area. Temperature extremes at either end of the spectrum could severely limit the total number and species of fish capable of consistently exploiting certain habitats (Rummer *et al.,* 2009). One study investigating seasonal and diel changes in a subtropical mangrove fish assemblage, similar to that found in Oleta River, revealed that water temperature best explained variation in species richness and diversity. Similar to the present study, this similar investigation also reported that water temperature displayed a positive correlation with species richness and diversity (Lin and Shao, 1999). In investigating global patterns of species richness, it was determined that water temperature was the only predictor of species richness identified as statistically significant across all species groups of mangrove fishes (Tittensor *et al*., 2010). Also, analogous to the present study, are species specific reports of correlations with water temperature. Serafy *et al*. (2007) reported that gray snapper (*L. griseus*) occurrence and density increased with increasing water temperatures. Numerous studies have reported that snapper show a high probability of capture in warmer waters of sub-tropical origin (Leathwick *et al*., 2004).

DISTANCE FROM INLET

A possible explanation for greater taxonomic richness and overall abundance of fishes found in study sites closer to Baker's Haulover Inlet, exists in the respective proximity (distance from Baker's Haulover Inlet) of each survey site to offshore reef habitats and areas characterized by higher salinity conditions. It has been previously noted that fish of mangrove habitats vary greatly in taxonomic composition and overall abundance in part as result of relative location to different habitats, including coral reefs (Laegdesgaard and Johnson, 2001). Connectivity between mangrove fish assemblages and those associated with coral reef communities is likely to depend not only on the distance between the two habitats, but also on the presence of movement corridors or "stepping-stones" of a natural habitat. Based on the presence of such reef related taxa as parrotfish and grunts discovered with the mangrove shoreline of Oleta River, it appears that Baker's Haulover Inlet provides a form of passage for these reef related taxa to migrate through the inlet and into the mangrove habitat. Knowledge of this connectivity between fish populations and determination of potential habitats that supply more recruits to adult populations have considerable implications for fisheries management and the effective conservation of various fish species (Gillanders *et al*., 2003).

Similar findings have been revealed in previous studies investigating potential changes in taxonomic richness and abundance with increasing distance from larger marine habitats. In a study conducted in a tropical mangrove estuary located in Taiwan, it was discovered that distribution patterns, taxonomic richness and overall abundance of fishes showed a clear decrease with increasing distance from the mouth of the river and into a more upstream area (Tzeng and Wang, 1992). A separate study, investigating fish communities in tropical mangrove creeks in Trat Bay, Thailand, revealed that overall abundance and species richness of fish declined over distance from downstream to upstream in all of the creeks examined (Singkran and Sudara, 2005).

SALINITY

In mangrove estuaries, salinity is often an important environmental factor structuring fish assemblages (Quinn and Kojis, 1985). It has been widely noted in previous studies that water salinity is a major hydrobiological factor which is strongly influenced by climate and can greatly effect fish distributions, habitat heterogeneity and community biodiversity (Gilmore, 1995). Wells (1985) hypothesized that estuaries or areas of water which remained virtually fresh throughout the year would have fewer mangrove species than those which were brackish or underwent seasonal fluctuations in salinity. As was mentioned, salinity in Oleta River decreased with increasing distance from Baker's Haulover Inlet. This could potentially explain why higher taxonomic richness and a greater density of the five most abundant taxa were displayed at study sites located closer to Baker's Haulover Inlet. When the potential correlation between species richness and salinity was examined throughout tropical coastal lagoons, it was discovered that when compared to various environmental variables, salinity was significantly and consistently related to fish species richness (Sosa-López *et al*., 2007).

An investigation into fish assemblages of the Indian River Lagoon (IRL), Florida revealed that salinity along with distance from Sebastian Inlet were the most consistent indicators of species groupings among the 40 most abundant fish in the IRL (Kupschus and Tremain, 2001). A similar study, also conducted in the IRL, described that the polyhaline to marine salinity environment present in the IRL allows a variety of marine species to enter the lagoon which may be excluded from estuaries with lower salinity regimes and oligohaline conditions.

AVERAGE DEPTH

It could be predicted that higher levels of overall abundance and taxonomic richness should usually be associated with greater water depths associated with flood and high tides. In a study focusing on species richness and habitat complexity, it was noted that as the tide rises in coastal estuaries, pelagic, reef-related fish species could use the opportunity to enter the mangrove habitat for shelter or food, resulting in higher species richness and abundance around the connecting source (e.g. mouth of river or inlet) (Gratwicke and Speight, 2005). Similarly, in a study on fish use of subtropical marshes, species richness and densities of certain species were positively related to water depth. Throughout the dry season, water depth alone was found to be a better predictor of fish density in a majority of recorded cases. In all cases, the relationship between fish density and water depth was positive, increasing with increasing water depth (Thomas and Connolly, 2001). A study investigating patterns in community structure of a Caribbean bay (Nagelkerken *et al*., 2000) reported total fish density, density of different species groups and species richness in bay biotopes were in most cases related to water depth in addition to water clarity and distance to mouth. This particular study attributed the positive relationship with water depth to an increase in shelter space (Nagelkerken *et al*., 2000). In a similar investigation, Morton *et al*. (1987) found that water depth in a tidal inlet was positively related to total fish abundance and species richness, with more fish and a higher number of species entering the creek during higher tides. While the present study tried to account for possible tidal fluctuations in overall abundance and species richness, it would be beneficial to look more closely at the potential correlation between tides and taxonomic richness and overall abundance.

In the present study, abundance of *Eucinostomus* sp. displayed a negative correlation with water depth, with their presence decreasing in the mangroves with increasing water depth. Since the surveys conducted for the present study were performed during high tide, this finding could possible be explained by the concept of tidal migration mentioned above. This concept suggests that fish migrate into shallow flats at high tide and off into deeper water as the tide recedes in an effort to avoid stranding in shallow waters (Sogard *et al.*, 1989). It is believed that the attraction of shallow waters to fishes is evident in the rapid colonization of newly available habitat created by rising water levels (Russel and Garret, 1983).

WATER CLARITY

Out of all of the microhabitat variables investigated for the present study, it appeared that water clarity had the least influence in determining taxonomic richness or abundance of the top 5 species. Blaber and Blaber (1980) argued that water clarity has a significant negative relationship with abundance of mangrove associated fishes in inshore waters, with turbid water providing greater protection from potential predators. Similarly, it has been hypothesized that in turbid water, with lower water quality, the foraging efficiency of fish predators decreases, resulting in higher abundances of prey species (Robertson and Blaber, 1992).

CHAPTER 5: CONCLUSION

OVERVIEW

While the results of this study do provide some insight into the fish taxa inhabiting the mangrove shorelines of Oleta River State Park, there is still much to learn about which conditions are optimal for these particular taxa to thrive. Although previous studies have suggested that significant number of coral reef associated fish species have been found in surrounding mangrove habitats, data has proven to be difficult to collect and/or interpret for numerous reasons. Few non-destructive, quantitative assessments of whole fish communities seem to have been attempted in mangrove habitats. As was mentioned previously, logistical problems of sampling quantitatively among mangroves are severe and studies in those habitats tend to be not well quantified. The visual census survey utilized in this study has proven to be a rapid and effective technique for collecting data on the fish assemblages that occupy Oleta River's mangrove-lined shorelines. This technique is efficient for making quantitative comparisons of fish distribution, abundance and size-structure within and among habitat types. Advantages of this form of visual census are that they are rapid, non-destructive, and inexpensive. Visual surveys also allow the same areas can be resurveyed through time, and the results can be compared with many other studies (English *et al*., 1994). There are also disadvantages with this method of assessment, including inability to complete the survey in areas of low clarity, or those which are not easily accessible due to the mangroves themselves or due to severely shallow water depths (i.e., <10cm) (Serafy *et al*. 2003).

COMPARISONS

When compared with fish assemblages of Southern Biscayne Bay, the present study revealed that the fish communities found within the mangrove-lined shorelines of ORSP are relatively productive and diverse. While a similar study conducted in Southern Biscayne Bay by Serafy *et al*. (2003), reported a total number of species similar to the present study, the list displayed a different variety of fish taxa. The list compiled from the southern Biscayne Bay study revealed a total of 38 fish taxa while the present study conducted in northern Biscayne Bay reported a total of 37. The two studies shared 21 fish taxa. Taxa unique to Oleta River in northern Biscayne Bay included two parrotfish, spotted goatfish, bandtail searobin, a snapper, two grunts, two gobies, striped mojarra, shark remora, southern stingray, a jack, two Sparidae and scrawled cowfish. Taxa unique to southern Biscayne Bay include a drum, a chub, a cichlid, a jack, porcupine fish, a cowfish, smooth trunkfish, rainbow parrotfish, a snapper, sailfin molly, three killifishes, green moray and a nurse shark. Based on these discrepancies between lists, it appears that the taxonomic list compiled for northern Biscayne Bay reveals more reef associated species which may be considered unique to ORSP. This may be explained by the corridor provided by Baker's Haulover Inlet which allows reef associated taxa, including parrotfishes a point of access to the mangrove-lined shorelines of Oleta River. In comparing average taxonomic richness values, it was revealed that survey sites along the mainland of southern Biscayne Bay reported a lower degree of taxonomic richness (3.76 taxa per unit area) versus values recorded from Oleta River, which averaged 5.30 taxa per unit area. When compared to the mean taxonomic richness value recorded at leeward key sites in southern Biscayne Bay (7.42 taxa per unit area), it was discovered that mean taxonomic richness of Oleta River was relatively low (5.30 taxa per unit area).

There are some differences in comparing the top five dominant taxa between the two studies. While the top five dominant taxa of southern Biscayne Bay include small, water-column fishes, *Eucinostomus* sp. and gray snapper, similar to the present study, it also includes yellowfin mojarra and the goldspotted killifish. Average abundance of small, water-column fishes was discovered to be lower at the mainland of southern Biscayne Bay (332.13 per unit area) versus Oleta River (530 per unit area), but was lower than at the leeward key sites of southern Biscayne Bay (3,129.41 per unit area). *Eucinostomus* sp. displayed a higher mean taxonomic richness at ORSP (642.7 per unit area) when compared to mainland (54.78) and leeward key (29.42) values. Similarly, mean abundance of bluestriped grunt was highest at ORSP (23.01 per unit area) when compared to mainland (0.00) and leeward key (10.71) values. Average abundance of gray snapper was slightly higher at ORSP (3.83 per unit area) than that recoded at the mainland sites of southern Biscayne Bay (3.69), but was lower when compared to mean abundance recorded at leeward key sites (24.87). While mean abundance of sailors choice was higher at ORSP (2.32 per unit area) versus the mainland of southern Biscayne Bay (0.10), it was lower than that of the leeward key sites of southern Biscayne Bay (6.11).

Differences in mean taxonomic richness and abundance of the five numerically dominant taxa of ORSP could potentially be explained by habitat structure and composition. Higher mean taxonomic richness and higher abundances along ORSP shorelines relative to those along the mainland of southern Biscayne Bay may reflect the higher amounts of hard substrate, such as seawalls, bridges, pilings and riprap which are more concentrated in northern versus southern Biscayne Bay. For the most part, OSRP mangrove fish diversity and abundance was lower than the leeward keys sites of southern Biscayne Bay, which is has little or no artificial substrate. This may simply reflect proximity to the reef tract. ORSP and leeward key survey sites which documented higher taxonomic richness and abundance of the dominant taxa were situated closer to more open water marine areas with a higher degree of connection to reef associated fish communities. The mainland survey sites of southern Biscayne Bay, which displayed a lower mean taxonomic richness and overall abundance is located further inland, relatively more distance from the adjacent coral reef resources. The closer to the reef, the more reef fish there are along nearby shorelines. While man-made structures were previously thought to serve as a form of disturbance to fish assemblages, in many cases higher abundance of fishes are associated with the presence of bridges, seawalls and riprap (Davis *et al.*, 1982).

Although numerous studies have published trends of taxonomic richness and overall abundance of fish in highly urbanized areas, few have been conducted in sub-tropical mangrove habitats similar to those found in Oleta River State Park. Based on the literature review conducted for the present study (Table 1), there is a great deficit in the amount of information available on fish assemblages and environmental data found within urbanized parks similar to Oleta River. The human population in Florida has consistently allowed for the highest terrestrial and aquatic native habitat destruction rate within the continental United States through coastal urbanization

(Gilmore, 1995). It is crucial that future studies focus their attention on these quickly declining subtropical mangrove habitats and how uncontrolled resource utilization will only further harm the environment and its inhabitants. With additional information on these highly threatened environments and the anthropogenic activities affecting them¸ management and mitigation programs can be created to better suit these habitats in efforts to restore them to a more natural, productive state.

Essential information could be provided by further investigating significant seasonal and microhabitat correlations revealed in the present study with those in similar studies. While previous studies have provided evidence suggesting strong correlations between temperature, salinity and taxonomic richness, taxa may also be responding to habitat characteristics unrelated to these variables, or possibly as a result of additional variables not discussed in this paper. An investigation into the relationship between seasonal variation of various microhabitat variables such as dissolved oxygen, and various nutrients found within Oleta River could provide more information and a better understanding of factors influencing taxonomic richness and overall abundance. It has been suggested that habitat size and patchiness have great influence on fish faunal species composition and population size (Gilmore, 1995). This could be more closely examined with a combination of visual field surveys, satellite imagery and geographic mapping technologies. As was previously mentioned, the utilization of laboratory investigations and additional field surveys could serve as useful indicators to variables which have already been accessed throughout this study and those which have not. Quantifying natural features important in structuring fish assemblages is a crucial pre-requisite to implementation of measures to conserve regionally representative ecosystems such as the mangrove shorelines of Oleta River (Ley, 2005). Continuous research is essential to determine the ideal size, number, total area and location of the potential expansion of marine reserves in order to achieve specific management goals

MANAGEMENT APPLICATIONS

As one of the most threatened major environments on earth, destruction of mangrove forests has received scant public and political attention. It is crucial that comprehensive research aimed at assessing the status of mangroves in Biscayne Bay is undertaken as well as restoration and conservation efforts that will impel public and political notice of the true severity of the issue (Valiela *et al*. 2001). Results presented in this study could potentially be utilized to support management programs taking an approach aimed at conserving the biodiversity of estuarine fish assemblages by combining regional and estuary scales in defining networks of reserve systems (Ley, 2005).

While Oleta River State Park is considered to be an essential, unique component of Biscayne Bay's marine preserve system, few, if any efforts are being made to closely monitor the type and amount of marine life being taken from the park on a regular basis. Established in 1974, the main goal of the Biscayne Bay aquatic preserve was established by the Florida Legislature "to be preserved in an essentially natural condition so that its biological and aesthetic values may endure for the enjoyment of future generations (Fl. Gen. Laws Ch. 258.397). Unless marine resources taken from Oleta River are more closely monitored, existing fish stocks of the park and those which are similar will continue to be depleted until this gap in management efforts is repaired.

One strategy which could potentially ensure more stringent monitoring and mitigation of mangrove fish assemblages of Oleta River would involve the implementation of “no-take” marine reserve zones throughout the park. Marine reserves, areas that are closed to all fishing, have been attracting much attention for their dual potential as conservation and fishery management tools. Reserves have been proposed as an efficient and inexpensive way to maintain and manage fisheries while simultaneously preserving biodiversity and meeting other conservation objectives as well as human needs (Plan Development Team [PDT] 1990; Halpern, 2003). In Florida, marine reserves in northern portions of the state have reportedly protected estuarine habitats and relatively mobile fish species, having supplied recreational fisheries with record size fish (Roberts *et al.*, 2001). Widespread interest has developed among managers, scientists and stakeholders in exploring the potential utility of using “no-take” marine protected areas (MPAs) to rebuild depleted fish stocks, conserve marine biodiversity and reduce conflicts among different resource users (Bohnsack and Ault, 1996). While increases in abundance and diversity after reserve establishment do not serve as a return to what are considered “pristine” conditions, reserves have shown to be effective in reducing habitat destruction and direct human-induced mortality on certain species within reserves (Halpern and Warner, 2003). Previous investigations into effectiveness of marine reserve design and spatial control of fishing impacts have determined that the effect of reserve implementation on stock sustainability was highly dependent upon the location of closures in relation to a species habitat use pattern. It has been observed that reserves placed in highly productive habitats, defined by high associated resource abundance, increased spawning potential ratio (SPR) over time due to the displacement of fishing effort to less productive habitats. Conversely, reserves placed in less productive habitats displaced fishing effort to more productive habitats, resulting in decreased SPR over time (Bartholomew and Bohnsack, 2005). Based on this finding, it would be beneficial to use the results of the present study in determining the zonation of potential no-take areas for ORSP. More highly populated sites identified through the present study, including those which are positioned closer to Baker's Haulover Inlet could be deemed "no-take" zones, allowing various reef related fish taxa identified through visual census surveys to continue utilizing the nearby mangrove-lined shorelines of Oleta River.

The greatest challenge in creating a management strategy for ORSP lies in promoting the use of the park for various stakeholders while conserving the parks natural resources. Generally, all stakeholder groups have the common goal of sustainability at the lowest cost (or maximum benefit) although exactly what they want to sustain differs dramatically between groups (Halpern and Warner, 2003). For example, groups who profit from non-extractive human activity (e.g. snorkeling, ecosystem organizations) realize and often stress the need to preserve and enhance the biological resources inside reserves, and ensure them against future degradation (Snelgrove, 1999).

A study by Suman *et al.* (1999) investigated the response of various interest groups including commercial fishers, dive operators and members of local environmental groups regarding perception and acceptance of the Florida Keys National Marine Sanctuary (FKNMS) zoning plan. This particular study revealed that support for the marine sanctuary varied significantly by stakeholder group, with a majority of environmental group members and dive operators supporting the establishment of the sanctuary while only a small percentage of commercial fishers were FKNMS proponents. While "no-take" marine reserve areas have been proposed as an efficient and inexpensive way to maintain and manage fisheries (Halpern, 2003), certain stakeholder groups, namely fishermen, may demonstrate a high degree of opposition to the planning and implementation of designated no-take zones (Suman *et al*., 1999). The ultimate goal for resource managers must be to convince stakeholder groups to embrace marine preserves, such as ORSP, as their own and comprehend the relevance of these natural areas to their groups interests (Kelly, 1992)

The only way to ensure that these practices will work from a policy standpoint, is by informing the public along with the other various stakeholders involved in Oleta River State Park, of the diverse fish community which many may fail to consider when planning the future use of the park and its natural resources (Ley *et al*., 1999; Faunce *et al*., 2002). Educating the public about the importance of mangrove habitats in a highly urbanized setting will ensure that those who visit Oleta River State Park will be more likely to respect and not exploit the many valuable natural resources that the park has to offer. It is well known throughout the scientific community that mangrove forests play various roles in the environment, serving as fertile habitats for foraging, breeding and sheltering for various kinds of animals including fish, crustaceans, birds, reptiles and mammals (Alongi, 2002). Programs such as the nonprofit organization Watchable Wildlife Inc. could be employed to spread knowledge to the community in a way that would encourage use of the park but would enhance the publics understanding of the importance of respecting the park as a natural habitat. The main objective of this organization is to put the public in touch with strategies for providing positive wildlife viewing experiences while informing visitors and local residents of the policy and management plans associated with the park in a manner that the public will best understand.

One strategy that can be employed to better communicate with the public would be posting signs in both English and Spanish that would further explain the importance of the mangrove habitat and the various taxa associated with the surrounding environment. Mapping fish community dynamics, as well as seasonal and microhabitat data is an efficient method in showing the public what Oleta River State Park truly has to offer (Bohnsack and Ault, 1996). In addition to displaying information on local flora and fauna, the signs can incorporate material concerning rules and regulations that come along with various protected and monitored species that inhabit Oleta River.

Aside from increasing monitoring effects throughout ORSP, it would also be beneficial to promote more sustainable fishing practices to visitors who visit the park for this purpose. Spatial demographic models created by previous studied have shown the potential success in pairing traditional control measures including establishing seasons, gear restrictions and quotas with spatial closures in efforts to secure fishery sustainability (Ault *et al.*, 2005). Catch and release and fly fishing are both well established practices in recreational fishing behavior and fisheries management. Furthermore, another approach is the promotion of the use of circle hooks. Circle hooks can effectively reduce deep hooking and mortality compared to the more commonly used J-hooks for many species (Cooke and Suski, 2004). Since circle hooks commonly lodge in the corner of a fishes mouth, they are usually easier to remove, reducing handling time and stress when practicing the catch and release method (Bartholomew and Bohnsack, 2005). Through promotion of better catch and release practices, strategies could be utilized to further minimize stress, injury and mortality to the current fish assemblages of ORSP. These efforts, when integrated with the fish population characteristics detailed by this study, can be used by fishermen and managers to sustain and even enhance recreational fishing resources within ORSP (Cooke and Schramm, 2007).

Habitat alterations, including those associated with the mentioned Everglades Restoration Plan, could potentially lead to the continued loss and degradation of mangrove habitats which have previously occurred throughout the shoreline of Biscayne Bay, Fl. This combination of anthropogenic and natural impacts commonly found in urbanized ecosystems have likely reduced the productive capacity of the ecosystem for sustaining populations of various commercially significant taxa including groupers and snappers. The challenge to achieving long term fish sustainability requires new scientific approaches and management measures commensurate with the rising complexity of human-ecosystem interactions (Ault *et al.*, 2005).

With the destruction of mangrove habitats continuing to occur globally, some efforts are being made to ensure the mitigation and future prevention of further loss. In the 2008 ORSP Unit Management Plan, a number of environmental management needs and current issues are listed. Proposed improvements to the park include: (1) enlarging existing fringe mangrove areas wherever possible; (2) establishing a regular water quality monitoring program for the park to include the mangrove preserve adjacent to the Munisport landfill and (3) organizing continuous surveys of submerged communities in order to determine the abundance and location of listed and unknown species. Although these efforts will not prevent the further expansion and urbanization of the already heavily developed city area surrounding ORSP, they will provide some guidance in maintaining the natural systems, including the mangrove forest communities, found throughout Oleta River.

The investigation described and discussed in this thesis is a baseline study. There are still many questions left unanswered concerning the current status and future of this highly urbanized, subtropical mangrove habitat. Ecological and biological effects generated by anthropogenically-driven alterations to Oleta River State Park over the years are still poorly understood. Due to this gap in knowledge, it is also unclear how coastal marine species will respond to additional changes to the coastal mangrove habitats in the future. Information presented by the present study, along with lessons learned by continuous surveys, can be considered crucial in the planning and implementation of future Unit Management Plans for Oleta River State Park and Everglades Restoration effort, as well as for other mangrove systems around the world.

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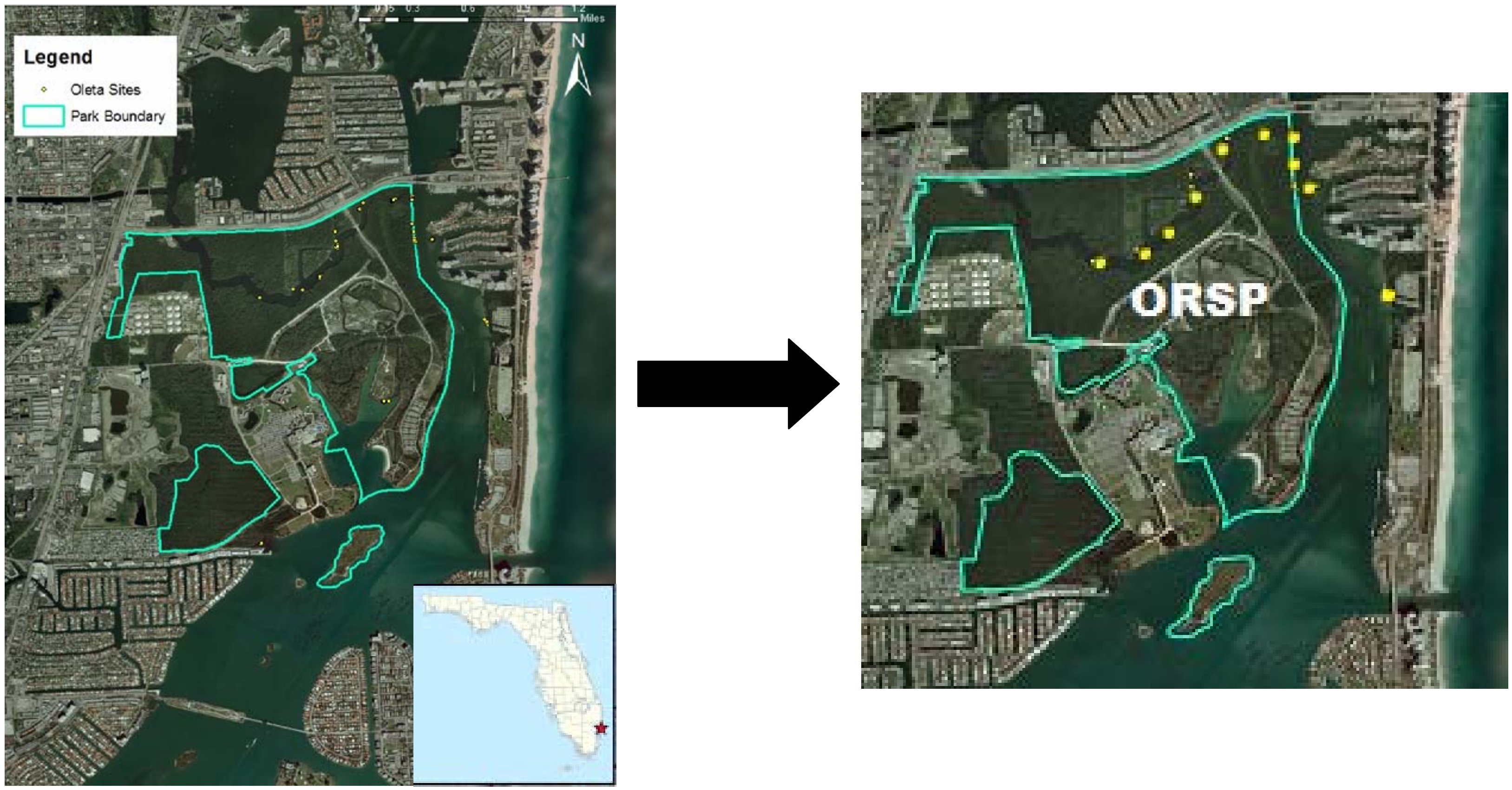


Figure 1. Location of Oleta River State Park on Florida’s (USA) coastline (inset) and a map depicting the location of visual censuses (2005-2010). Circles depict visual transect locations along the mangrove shoreline. Solid lines indicate the boundary of Oleta River State Park.

Table 1. Comparison of studies investigating fish populations in highly urbanized areas. Included is a comparison of location, habitat type and sampling techniques. Also displayed is the presence (Y) or absence (N) of a number of topics addressed in the present study. Each study was assessed for the presence of the following topics: focus on state parks, species lists, species richness, abundance and size range assessment, examination of microhabitat variables (MV), assessment of potential gradient, seasonal comparisons, maps, and literature reviews.

Source	Date	Title	Location(s)	Habitat type	Methodolgy	State Park	Sp. List	Sp. Richness	Abundance	Size Range	MV	Gradient	Seasonal	Maps	Lit Review	Economic
Present Study	2010	Mangrove shoreline fish assemblages of Oleta River State Park: baseline conditions in an urbanized mangrove ecosystem	Oleta River State Park, Biscayne Bay, Florida	Subtropical mangrove estuary	Visual census (belt transects)	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N
Alexandre, et al.	2010	Analysis of fish communities along a rural-to-urban gradient in a neotropical stream	Sao Paulo, Brazil	Tropical stream, estuarine	Electrofishing	N	Y	Y	Y	N	Y	Y	Y	Y	N	N
Aswani and Sabetian	2010	Implications of *Urbanization* for Artisanal Parrotfish Fisheries in the Western Solomon Islands	Western Soloman Islands	Marine, Coral reefs	Visual census (belt transects), Interviews	N	Y	N	Y	Y	N	Y	N	Y	N	Y
Chagas, et al.	2006	Small-scale spatial changes in estuarine fish: subtidal assemblages in estuarine fish: subtidal assemblages in tropical Brazil	Baia de Vitoria, Brazil	Estuarine gradient	Deep subtidal flats	N	Y	Y	Y	N	Y	Y	Y	Y	N	N
Clynick	2008	Characteristics of an urban fish assemblage: Distribution of fish associated with coastal marinas	waterways around Sydney, Australia	Marine waterways, urban marinas	Visual survey census, stationary point counts	N	Y	Y	Y	N	N	N	Y	Y	N	N
Clynick and Chapman	2002	Assemblages of small fish in patchy mangrove forests in Sydney Harbour	Sydney Harbour, Australia	Mangrove forests and mudflats near urban areas	Fyke nets, fish counts	Y	Y	Y	Y	N	N	N	Y	Y	N	N
Driver, et al.	2009	Fish assemblage of a cypress wetland within an urban landscape	Gillam Park Wetland in AR.	Cypress wetland, watershed	Fyke nets, fish counts	Y	Y	Y	Y	N	N	N	N	Y	N	N
Kelaher, et al.	2008	Changes in benthic assemblages near boardwalks in temperate urban mangrove forests	Several locations around Sydney, Australia	Temperate mangrove forests	Visual survey, quadrats	N	Y	Y	Y	N	N	N	N	Y	N	N
Marchetti, et al.	2006	Effects of Urbanization on California's fish diversity	Watersheds throughout CA.	Freshwater, watersheds	presence/absense data	N	N	Y	N	N	N	N	N	Y	N	N
McEwen and Joy	2009	Differences in the distributions of freshwater fishes and decapod crustaceans in urban and forested streams in Aukland, New Zealand	Aukland, New Zealand	Streams with catchment land use dominated by urbanization	Lit review, use of data from existing studies	N	Y	Y	Y	N	N	Y	N	Y	Y	N
Miserendino, et al.	2008	Assessing urban impacts on water quality, benthic communities and fish in streams of the Andes Mountains, Patagonia (Argentina)	Andes Mountains, Patagonia (Argentina)	Temperate mountain rivers	Electrofishing, water quality	N	Y	Y	Y	N	Y	Y	Y	Y	N	N
O'Toole, et al.	2009	The effect of shoreline recreational angling activities on aquatic and riparian habitat within an urban environment: implications for conservation and management	Ottawa, Canada	angling vs. non-angling activity sites in urban areas	Interviews, visual surveys, quadrats, soil sampling, water qaulity sampling	Y	N	Y	Y	N	Y	N	N	N	N	N
Paukert and Makinster	2009	Longitudinal patterns in flathead catfish relative abundance and length at age within a large river: Effects of an urban gradient	Kansas river, Junction city, Kansas	Riparian river	Electrofishing, fish count and ID	N	N	N	Y	Y	N	Y	N	Y	N	N
Rocha and Rosa	2005	Baseline assessment of reef fish assemblages of Parcel Manuel Luiz Marine State Park	north-east Brazil	Marine, Coral reefs	Visual census, some spear and net sampling	Y	Y	Y	Y	N	N	N	N	Y	N	N

Source	Date	Title	Location(s)	Habitat type	Methodolgy	State Park	Sp. List	Sp. Richness	Abundance	Size Range	MV	Gradient	Seasonal	Maps	Lit Review	Economic
Roth, et al.	1996	Landscape influences on stream biotic integrity assessed at multiple spatial scales	southeastern Michigan	Largely agricultural midwestern watershed	Electrofishing, Index of Biotic Integrity, Habitat Index, aerial analysis	N	N	Y	N	N	N	Y	N	Y	N	N
Rutheford, et al.	1989	Early life history of spotted sea trout and gray snapper in Florida Bay, Everglades National Park, Florida	Florida Bay, Everglades National Park, Florida	Subtropical estuary	Literature review, seign, water samples	Y	Y	N	Y	Y	Y	N	Y	Y	Y	N
Scott, et al.	1986	Effects of urban development on fish population dynamics in Kelsey Creek, Washington	Kelsey Creek, Washington	Urbanized vs. pristine watersheds	Fyke nets, fish counts, electrofishing	N	N	Y	Y	Y	Y	Y	Y	Y	N	N
Slawski, et al.	2008	Effects of Tributary Spatial Position, Urbanization, and Multiple Low Head Dams on Warmwater Fish Community Structure in a Midwestern Stream	Des Plaines, WI., IL.	Freshwater, streams	Electrofishing, fish count	N	Y	Y	Y	N	N	Y	N	Y	N	N
Viana, et al.	2010	Fish fauna as an indicator of environmental quality in an urbanised region of the Amazon estuary	Guajara Bay, Brazil	Estuarine bay near urban city	Gill nets, hand catch, fish count	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N
Wang, et al.	2001	Impacts of urbanization on stream habitat and fish across multiple spatial scales	southeastern Wisconsin	watersheds near agricultural and urban land	Electrofishing, fish count, historical land-use data	N	N	Y	N	N	N	Y	N	N	N	N
Wang, et al.	2003	Watershed, reach, and riparian influences on stream fish assemblages in the northern lakes and forest ecoregion, USA	Northern Lakes and Forest Ecoregion in the north-central US	watersheds in an undegraded US ecoregion	Electriofishing, fish count and ID, water quality sampling	N	Y	Y	Y	N	Y	Y	Y	Y	N	N
Wolter	2010	Functional vs. scenic restoration - challenges to improve fish and fisheries in urban waters	Two streams in Berlin	Freshwater, streams	Electric fishing, fish count and measure	N	Y	Y	Y	Y	N	Y	N	Y	Y	N
Walters, et al.	2003	Urbanization, sedimentation, and the homogenization of fish assemblages in the Etowah River Basin, USA	Etowah River in northern GA	Freshwater streams	Electrofishing, fish count and ID	N	N	Y	Y	Y	Y	N	N	N	N	N
Roy, et al.	2007	Riparian influences on stream fish assemblage structure in urbanizing streams	Etowah River basin in northern GA	Freshwater streams	Electrofishing, seine, spatial extent analysis	N	Y	Y	Y	N	N	N	N	Y	Y	N
Malcolm, et al.	2010	Use of patterns of reef fish assemblages to refine a Habitat Classification System for marine parks in NSW, Australia	Solitary Islands Marine Park in New South Whales, Australia	Marine park in a tropical-temperate biotone	Visual surveys, timed counts	Y	N	Y	Y	N	N	N	N	Y	N	N
Matzen and Berge	2008	Assessing small-stream biotic integrity using fish assemblages across an urban landscape in the Puget Sound Lowlands of Western Washington	Puget Sound Lowlands of Western Washington	Freshwater watershed	Electrofishing, fish count, ID, Index development , geomorphic characterization	N	Y	N	Y	N	N	Y	N	Y	Y	N
Weaver and Garman	1994	Urbanization of a watershed and historical changes in a stream fish assemblage	Tuckahoe Creek, Virginia	Warmwater stream and wetland	Electrofishing, seine, historical data	N	Y	Y	Y	N	N	N	N	N	Y	N
Morgan and Cushman	2005	Urbanization effects on stream fish assemblages in Maryland, USA	East Piedmont and Coastal Plain physiographic ecoregions of Maryland	Small freshwater streams	Data used from Maryland Biological Stream Survey Database, electrofishing, block nets	N	Y	Y	Y	N	N	Y	N	Y	Y	N
Rachlin, et al.	2007	An evaluation of the icthyofauna of the Bronx River, A resilient urban waterway	Bronx River, NY	Freshwater and estuarine sectins of an urbanized river	Literature review, historical data, electrofishing, seine nets	N	Y	Y	Y	N	N	Y	Y	Y	Y	N

Table 2. List of fish taxa observed via 60 m^2 visual belt transects along Biscayne Bay's (Florida, USA) Oleta River State Park mangrove shorelines from 2005 to 2010.

Family	Taxon	Common Name	Number Observed			Total Length (in)		
			Dry	Wet	Total	Min.	Mean	Max.
Pomacentridae	*Abudefduf saxatulis*	Sergeant Major	2	29	31	1	2	3
Ostraciidae	*Acanthostracion quadricornis*	Scrawled Cowfish	1		1	16	16	16
Antherinidae	*Silverside sp.*	Unknown Silverside	33376	35017	68393	0.5	2	3.5
Sparidae	*Archosargus probatocephalus*	Sheepshead	4	1	5	13	19.5	26
	Archosargus rhomboidalis	Sea Bream	1	3	4	4	6	8
	Diplodus holbrooki	Spottail Pinfish	1	4	5	4	4.5	5
	Lagodon rhomboides	Pinfish	4	22	26	3	7.5	12
Carangidae	*Caranx hippos*	Crevalle Jack		14	14	10	13	16
Centropomidae	*Centropomus undecimalis*	Common Snook	4		4	19	24.5	30
Dasyatidae	*Dasyatis americana*	Southern Stingray	1	5	6	10	27.5	45
Echeneidae	*Echeneis naucrates*	Shark Remora	1		1	11	11	11
Cyprinodontidae	*Floridichthys carpio*	Goldspotted Killifish		21	21	0.5	1.25	2
Gerreidae	*Diapterus plumieri*	Striped Mojarra		12	12	1	3	5
	Gerres cinereus	Yellowfin Mojarra	62	111	173	1	7	13
	Eucinostomus sp.	Eucinostomid mojarra	1030	1006	2036	0.250	2.625	5
Gobiidae	*Gobiidae sp.*	Common Goby	5		5	1	1.5	2
	Lophogobius cyprinoides	Crested Goby	52	17	69	1	2	3
Haemulidae	*Anisotremus virginicus*	Porkfish		1	1	5	5	5
	Haemulon carbonarium	Caesar Grunt		1	1	5	5	5
	Haemulon flavolineatum	French Grunt	2		2	3	3	3
	Haemulon parra	Sailors Choice	83	136	219	1	5.5	11
	Haemulon sciurus	Bluestriped Grunt	87	413	500	1	2.5	4
	Haemulon sp.	Unknown Grunt	61	25	86	0.5	2.25	4
Lutjanidae	*Lutjanus apodus*	Schoolmaster	5	54	59	2	6.5	11
	Lutjanus griseus	Gray Snapper	118	244	362	1	8.5	17
	Lutjanus jocu	Dog Snapper		1	1	3	3	3
Mugilidae	*Mugil cephalus*	Striped Mullet	40		40	9	10	11
Triglidae	*Prionotus ophryas*	Bandtail Searobin		1	1	7	7	7
Mullidae	*Pseudupeneus maculatus*	Spotted Goatfish	1		1	3	3	3
Scaridae	*Scarus sp.*	Unknown Scarus		5	5	5	6.5	8
	Scarus vetula	Queen Parrotfish		1	1	10	10	10
	Sparisoma aurofrenatum	Redband Parrotfish		1	1	2	2	2
	Sparisoma viride	Stoplight parrotfish		2	2	6	7.5	8
Sphyraenidae	*Sphyraena barracuda*	Great Barracuda	19	47	66	1	12	23
Tetraodontidae	*Sphoeroides testudineus*	Checkered Puffer	57	22	79	2	7.5	13
Belonidae	*Strongylura notata*	Redfin Needlefish		2	2	6	6	6
Urolophidae	*Urolophus jamaicensis*	Yellow Stingray		2	2	10	11	12

Table 3: Comparisons of fish taxonomic richness (number of fish taxa per unit area) and the densities of five dominant fish taxa observed throughout the wet and dry seasons along the mangrove shorelines of Oleta River in Biscayne Bay, Florida, USA. Values are means per season. For fish taxonomic richness values and taxon-specific density comparisons, non-parametric Kruskal Wallis tests were performed. One, two or three asterisks indicate statistical significance at the $P < 0.05$, $P < 0.01$ and $P < 0.001$ levels, respectively. ns = not significant.

		2005			**2006**			**2007**			**2008**			**2009**	
	Dry	Wet	p	Dry	Wet	p	Dry	Wet	p	Dry	Wet	p	Dry	Wet	p
n	6	8		8	9		10	8		10	10		10	10	
Taxonomic Richness	4.83	7.13	*	4.88	6.78	ns	3.80	7.00	**	4.30	5.20	ns	4.60	4.50	ns
Clupeidae/Engraulidae/Atherinidae	203.33	274.00	ns	903.13	900.00	ns	216.00	1965.50	*	871.10	444.55	ns	607.10	43.00	***
Eucinostomus sp.	48.67	20.00	ns	14.63	54.56	ns	15.40	26.70	ns	26.70	2.20	***	7.00	14.20	ns
bluestriped grunt	4.17	6.13	ns	0.71	0.63	ns	0.00	13.00	***	1.80	4.20	ns	1.80	5.90	ns
gray snapper	0.67	2.25	ns	4.75	8.11	*	0.90	7.90	*	0.60	4.10	ns	2.60	3.30	ns
sailors choice	1.33	1.63	ns	7.75	0.00	ns	0.00	6.60	*	0.20	5.50	ns	0.00	0.20	ns

Table 4. Correlations of ranked values of fish taxonomic richness (number of fish taxa per unit area) and ranked densities of five dominant fish taxa along with microhabitat variables (temperature, distance from inlet, salinity, average depth, and clarity) observed in Oleta River State Park in Biscayne Bay, Florida, USA. Multiple-regression analysis was performed. A plus (+) or minus (-) sign indicates a positive or negative relationship. One, two, three or four asterisks indicate statistical significant at the $P < 0.1$, $P < 0.05$, $P < 0.01$ and $P < 0.001$ levels, respectively.

	Temperature (°C)	**Distance (km)**	**Salinity (ppt)**	**Average Depth (m)**	**Clarity (m)**
Taxonomic Richness	(+) ****	(-) **	(+) **	ns	ns
Clupeidae/Engraulidae/Atherinidae	ns	(-) **	ns	(+) **	ns
Eucinostomus sp.	ns	ns	ns	(-) *	ns
bluestriped grunt	(+) ****	ns	ns	ns	(+) *
gray snapper	(+) **	ns	ns	ns	ns
sailors choice	(+) *	ns	ns	ns	ns

Table 5. Seasonal comparisons of mean microhabitat variables recorded along the mangrove shorelines of Oleta River State Park. Mean temperature, salinity, clarity and average depth were calculated for the wet (July to September) and dry (January to March) seasons of 2005-2009. Kruskal-Wallis tests were performed for seasonal comparisons. One, two or three asterisks indicate statistical significant at the $P < 0.05$, $P < 0.01$ and $P < 0.001$ levels, respectively. ns = not significant.

	2005			**2006**			**2007**			**2008**			**2009**		
	Dry	Wet	p	Dry	Wet	p	Dry	Wet	p	Dry	Wet	p	Dry	Wet	p
Temperature	23.48	30.98	**	23.29	30.14	**	24.63	30.44	***	24.74	31.42	***	22.85	29.28	***
Salinity	34.93	30.51	ns	35.23	28.71	ns	31.65	29.61	ns	32.91	29.26	**	33.63	20.16	***
Clarity	2.58	3.41	***	3.44	3.25	ns	1.90	2.65	***	2.90	3.05	ns	2.60	2.15	ns
Average Depth	47.39	81.00	*	105.38	90.85	ns	68.00	108.42	ns	95.37	108.90	ns	101.03	92.60	**

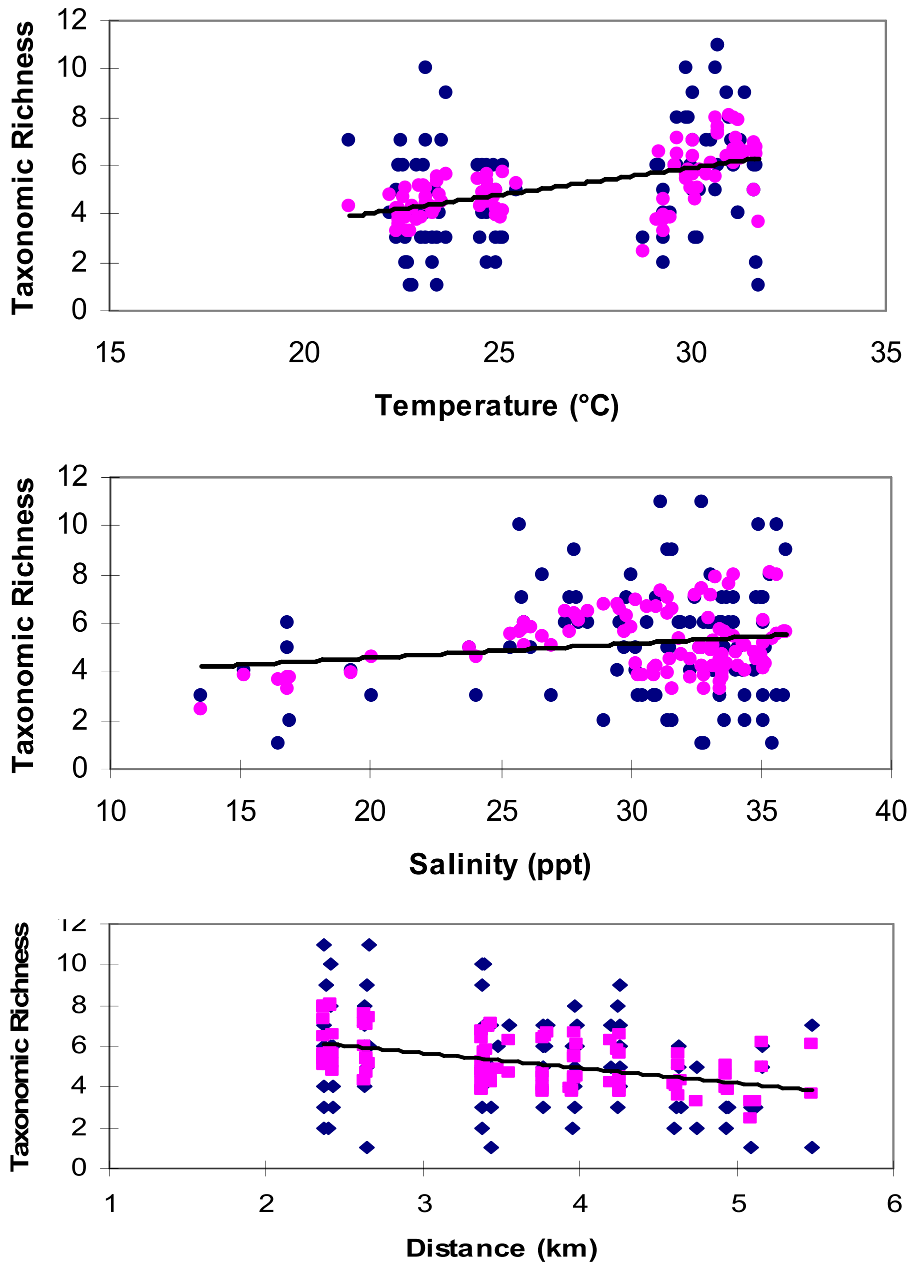
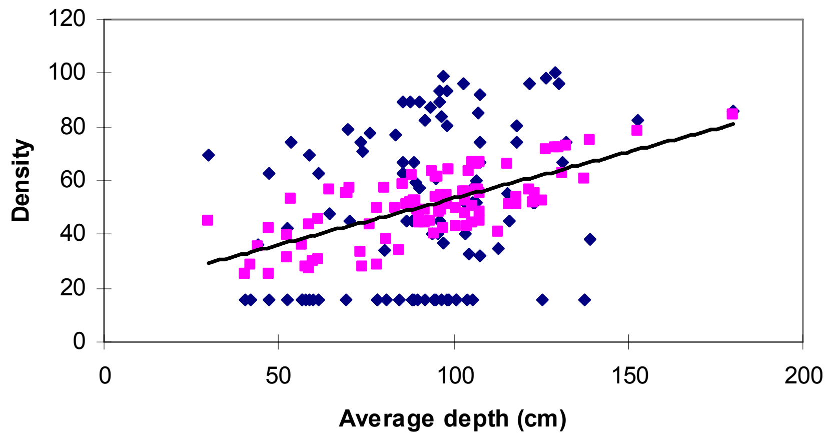


Figure 2. Scatter plots of observed (blue) and predicted (pink) taxonomic richness (number of fish taxa per unit area). Predicted values were obtained following multiple regression analyses whereby temperature, salinity, water clarity, depth and distance from inlet were included in initial models. In the event that a variable was found insignificant, it was removed and the regression re-run until all model terms were significant. Only significant relationships are plotted. Temperature (top), salinity (middle) and distance (bottom) were significantly correlated with taxonomic richness.



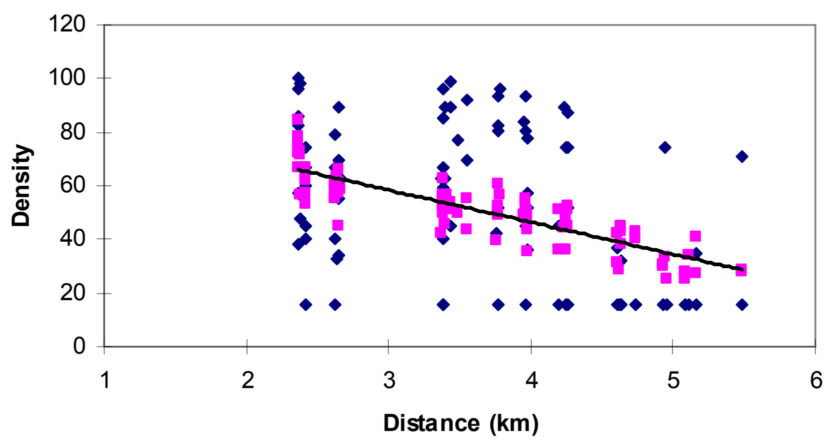


Figure 3. Scatter plots of observed (blue) and predicted small, water-column fish densities. Predicted values were obtained following multiple regression analyses whereby temperature, salinity, water clarity, depth and distance from inlet were included in initial models. In the even that a variable was found insignificant, it was removed and the regression re-run until all model terms were significant. Only significant relationships are plotted. Distance (top) and average depth (bottom) were significantly correlated with average abundance of small, water-column fishes.

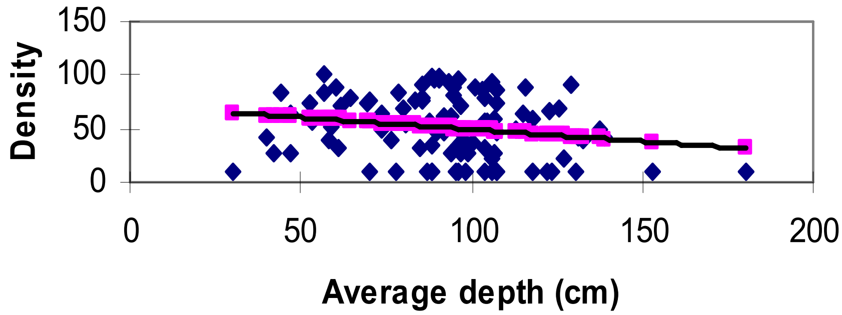


Figure 4. Scatter plot of observed (blue) and predicted (pink) *Eucinostomus sp.* densities. Predicted values were obtained following multiple regression analyses whereby temperature, salinity, water clarity, depth and distance from inlet were included in initial models. In the event that a variable was found insignificant, it was removed and the regression re-run until all model terms were significant. Only significant relationships are plotted. Density was significantly correlated with *Eucinostomus sp.*

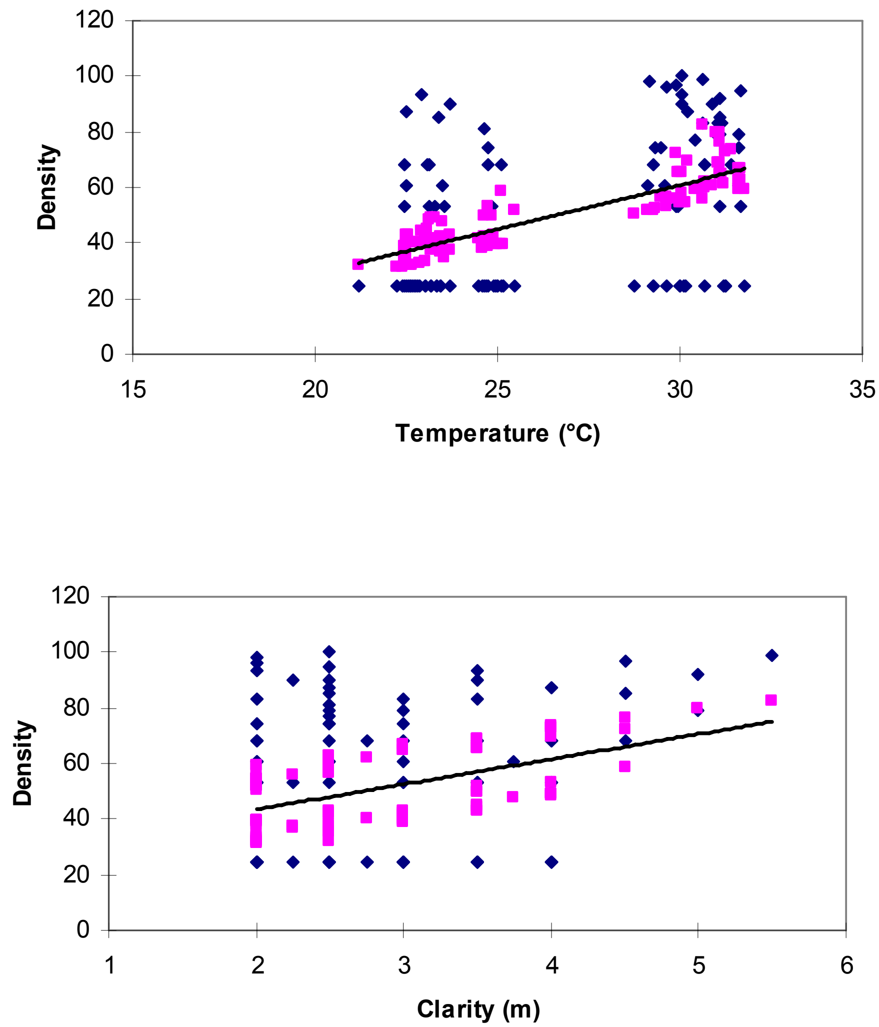


Figure 5. Scatter plots of observed (blue) and predicted (pink) bluestriped grunt, *H. sciurus* densities. Predicted values were obtained following multiple regression analyses whereby temperature, salinity, water clarity, depth and distance from inlet were included in initial models. In the event that a variable was found insignificant, it was removed and the regression re-run until all model terms were significant. Only significant relationships are plotted. Temperature (top) and water clarity (bottom) were significantly correlated with *H sciurus.*

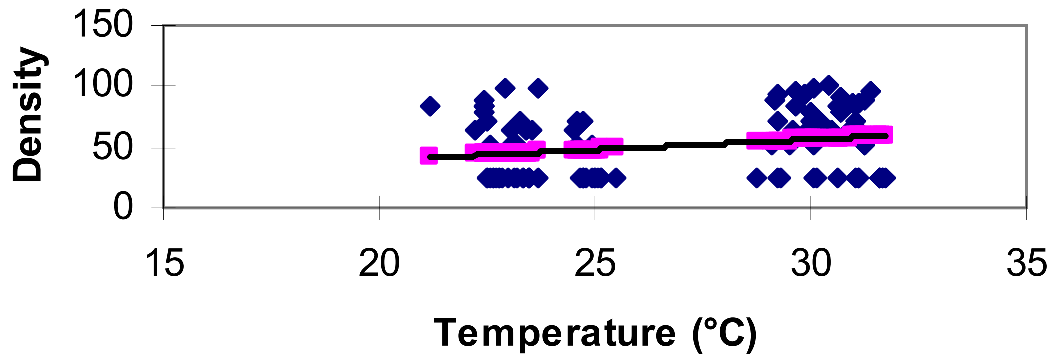


Figure 6. Scatter plot of observed (blue) and predicted (pink) gray snapper *L. griseus* densities. Predicted values were obtained following multiple regression analyses whereby temperature, salinity, water clarity, depth and distance from inlet were included in initial models. In the event that a variable was found insignificant, it was removed and the regression re-run until all model terms were significant. Only significant relationships are plotted. Temperature was significantly correlated with average abundance of *L. griseus.*

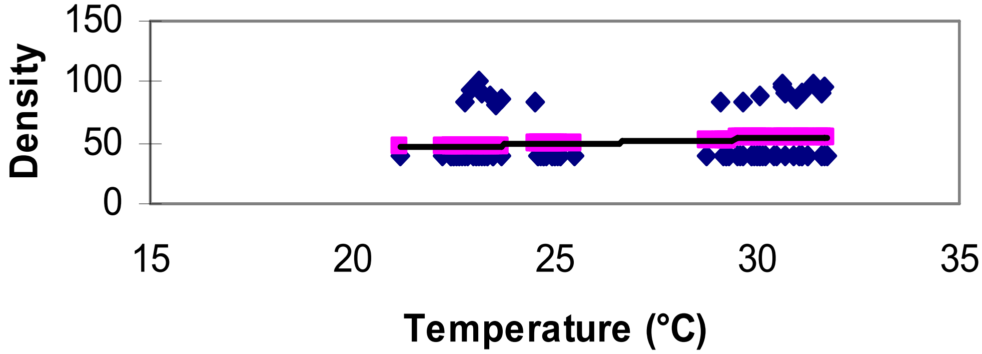


Figure 7. Scatter plots of observed (blue) and predicted (pink) sailors choice, *H. parra* densities. The predicted values were obtained following multiple regression analyses whereby temperature, salinity, water clarity, depth and distance from inlet were included in initial models. In the event that a variable was found insignificant, it was removed and the regression re-run until all model terms were significant. Only significant relationships are plotted. Temperature was significantly correlated with average abundance of *H. parra*.