Fish and Shellfish: Fish, Shrimp, and Crabs

Joan A. Browder
National Marine Fisheries Service/Southeast Fisheries Science Center

In a nutshell

- The SWFS region provides essential habitat for many kinds of fish, shellfish, and marine animals, including the endangered smalltooth sawfish, goliath grouper, bonnethead, blacktip, lemon and nursery sharks, the Kemp's ridley, green, leatherback, and Atlantic loggerhead sea turtles, and the West Indian manatee.
- The fish and shellfish resources of this region support valuable recreational and commercial fisheries.
- Freshwater inflow to the coast influences salinity, temperature, turbidity, nutrient concentrations, and other conditions that are important to the animals that depend on inshore habitat for food and as nursery areas.
- Water management practices adopted to promote expansion of agriculture and urban development throughout the South Florida region have altered the quantity, quality, timing, and distribution of freshwater inflows to the southwest Florida coast.

Define Resource

The fishery resources of the SWFS are highly valued and protected to various degrees by the Ten Thousand Islands National Wildlife Refuge, Rookery Bay National Estuarine Research Reserve, Fakahatchee State Park, and Everglades National Park. The fish and macroinvertebrate fauna of the Ten Thousand Islands support both recreational and commercial fishing. The short list of target species inshore includes snook, tarpon, red drum, spotted seatrout, pompano, and sharks. Offshore, the principal target species are snapper, grouper, cobia, permit, barracuda, king and Spanish mackerels, and more sharks.

The Ten Thousand Islands area west of Chokoloskee consists of a series of inner open water areas, called bays, separated from the Gulf of Mexico by a broader area of small mangrove islands surrounded by shallow water. The wetlands that grade into the bays from the uplands are covered primarily with red mangrove. Mangrove-lined passes connect the inner bays and inter-island areas with the Gulf of Mexico, except immediately south of Cape Romano where a large shallow open-water outer bay, Gullivan Bay, lies between the islands and the Gulf of Mexico. The easternmost and largest of the inner bays is Fakahatchee Bay, which historically received the natural freshwater discharge of East River and the Fakahatchee River, both of which are tributaries of Fakahatchee Strand and the Okaloacoochee Slough, a major natural shallow-water freshwater-flow system.

The principal sport fishing targets represent a small component of the fish and shellfish of Ten Thousand Islands waters. Inshore are many other fish that provide good opportunities for anglers, as well as a myriad of smaller fish that serve as bait for anglers and the prey of fishing targets. The first category includes spotted and sand seatrout, sheepshead porgy, and hardhead catfish. In a two-year trawl study of Faka Union, Fakahatchee, and Pumpkin bays, Browder *et al.* (1986) documented at

least 79 fish species and 70 macroinvertebrate species that fit the lower and middle levels of the faunal food web. Dominant fish were bay anchovy, yellowfin menhaden, scaled sardine, striped anchovy, pinfish, and silver perch. In a later three-year study of Faka Union and Fakahatchee bays and Henderson Creek, Shirley *et al.* (2005) listed as dominants spotfin mojarra, silver jenny, fringed flounder, pigfish, and blackcheeked tonguefish. Pink shrimp were among the numerically-dominant species in Shirley *et al.* (2005), and the total catch of pink shrimp was of similar magnitude in a 1972 trawl study of Fakahatchee and Faka Union bays by Carter *et al.* (1973). Pink shrimp were the second most abundant decapod, following caridean shrimp in abundance, in Browder *et al.* (1986). Species composition changes seasonally and varies by bay system (Shirley *et al.,* 2005).

Several species of special concern are a part of the aquatic fauna of this region. Southwest Florida is the last stronghold for the endangered smalltooth sawfish, and 619,013 acres of the combined Ten Thousand Islands and Everglades regions have been declared critical habitat for this species. Such designation requires "consultation" on permits and public works plans that might affect the habitat. Waters of the Ten Thousand Islands are also important habitat for the goliath grouper, once an important fishery species. The species was declared "economically overfished" in the early 1990s and placed off limits for fishing ever since. The West Indian manatee is another major endangered species living in the Ten Thousand Islands. Kemp's Ridley, green, leatherback, and Atlantic loggerhead sea turtles are other listed endangered species for which the Ten Thousand Islands are important habitat. These waters also provide nursery habitat for several species of sharks (Patrick Donnell, Mote Marine Laboratory, personal communication), including bonnethead, blacktip, lemon, and nursey sharks.

Role in Ecosystem

The Ten Thousand Islands are an important nursery area for many recreational and commercial species, including some harvested offshore. The Ten Thousand Islands waters are also habitat for resident species that spend their entire life cycle inshore and other species that use the Ten Thousand Islands as nursery grounds. The typical pattern for the latter is offshore spawning, followed by immigration of early life stages to inshore Ten Thousand Islands waters. There are many variations on this pattern. Spawning areas for some are near the outer SWFS; whereas other species spawn just outside the passes, and their eggs are carried inshore on currents. Some species occasionally found in the Ten Thousand Islands are not necessarily totally dependent upon these waters at any particular life history stage but take advantage of the productive and sheltered habitat they provide.

A combination of dynamic and structural features distinguish the habitat of fish and macroinvertebrates. Dynamic features include salinity ranges, nutrient gradients, and other factors that shift around and expand and contract with freshwater inflow and the tide. Structural habitat is fixed in space and associated with the bottom or the shoreline. In the Ten Thousand Islands, three of the most important types of structural habitat—mangrove prop root, seagrass, and oyster bar—are provided by living, or once living, organisms. Such habitat enhances feeding opportunities and provides protection from predators for many species. Habitat needs of individual species may be more specific within each habitat type. For example, mangrove prop root habitat may be tidal creek, edge of a bay, backwater side of an island, or the faster currents of passes, any one of which may be the preferred habitat of a species.

Predation is an important governing factor in ecosystems. By preying on other organisms, fish species operating at several trophic levels create pressures that influence ecosystem structure and function in many ways (Sih *et al.,* 1998), even affecting primary producers, including phytoplankton, epiphyton, and seagrasses. Because in even the simplest cases, fish are players in food webs, not food chains, a change in the abundance of one species can have reverberating consequences. The generally high productivity of estuaries attracts predators. The habitat structure in estuaries provides a counterbalance by providing prey with places to hide. Nevertheless, food supply probably is not limiting to the larger estuarine predators. The role of predation can be better understood by briefly describing some of our upper trophic level predators and some major prey items.

Red Drum

Red drum spawn in the fall (i.e., mid-August through early November) at the mouths of passes, and larvae settle out along the bayshore and then migrate toward low salinity backwater areas, including tidal creeks (Jannke, 1971; Peters and McMichael, 1987). Juvenile red drum gradually move back into the bay with increased size and age. Adults are found in more open waters, except at spawning time, when they move to the mouths of passes. According to Peters and McMichael (1987), red drum prey on copepods as larvae, shifting to mysids once they are >8 mm long and then to caridean and penaeid shrimps (including pink shrimp) when they are >75 mm long. Juveniles >90 mm long eat crabs and fish. Red drum are among the many mobile species that occur in association with oyster reefs.

Snook

The common snook is another important sport fish species of the Ten Thousand Islands. Carter *et al.* (1973) report that the main food items of juvenile snook in the Ten Thousand Islands, by volume, were fish (81 percent), shrimp (16 percent), and crab (2 percent). Dominant prey fish species were poeciliids, cyprinodonts, and atherinids. Younger juveniles ate a mix of zooplankton, fish, and palaemonid shrimp (Carter *et al.,* 1973). Other sport and commercial species found in tidal streams of the Ten Thousand Islands by Carter *et al.* (1973) were spotted searout (*Cynoscion nebulosus*), gray snapper (*Lutjanus griseus*), crevalle jack, sheepshead, striped mullet, pinfish, and striped mojarra.

Tarpon

The tarpon is an internationally renowned big game fish of southwest Florida. It is esteemed for its stamina, strength, and leaping prowness (Zale and Merrifield, 1989). Like many other fish found in southwest Florida estuaries, this species spawns offshore. Sexual maturity is attained at a total length of about 120 cm. Fecundity of a 2-m long female was estimated at 12.2 million eggs. The diet of tarpon changes through life. Stage 1 tarpon absorb nutrients integumentarily from seawater. Stages II and III feed on zooplankton. Juvenile tarpon progressively increase the size of their prey as they grow, feeding initially on insects, crabs, and grass shrimps of the genus *Palaemonetes*, and small fishes in the families Poeciliidae and Cyprinidonidae. Adult tarpon capture larger midwater fish prey, such as mullets, hardhead catfish, Atlantic needlefish, and sardines, as well as shrimp and crabs, which they swallow whole. The closely related lady fish has a similar life history and diet in younger stages but, due to its smaller adult size, does not advance to the larger prey. Although abundant, it is not a targeted sport fish.

Goliath Grouper

The Ten Thousand Islands are a recognized important juvenile nursery habitat for goliath grouper and the center of their distribution (Koening *et al.,* 2007). This species is the largest grouper in the western North Atlantic. It is found from nearshore waters out to depths of 70 m. The larvae settle in Florida estuaries in the fall, and the young are found along mangrove-lined creeks and tidal passes from settlement size up to about 1 meter long and an age of 6 or 7 years (Koenig *et al.,* 2007).

Sharks

The Ten Thousand Islands are an important nursery habitat for sharks. The bull shark is the most numerous shark in Faka Union Bay. It is capable of withstanding low salinities for long periods and moves freely between marine salinities and freshwater. Low salinities may exclude other shark species from entering Faka Union Bay during the wet season. Bonnethead sharks inhabit the Ten Thousand Islands throughout their lives, from neonate stage to adult. Blacktip sharks use the Ten Thousand Islands during their neonate, young of the year, and immature stages. Lemon sharks use the area in their young of the year and immature stages. Nurse sharks are found there in their immature stage.

Smalltooth Sawfish

Coastal mangrove estuaries between Charlotte Harbor and Florida Bay are recognized as premium nursery habitat for the U.S. distinct endangered population of smalltooth sawfish and have been declared "critical habitat" for this species by the National Marine Fisheries Service (effective October 2, 2009, *Federal Register*, Vol. 74, No. 169, pp. 45,353-45,377). This tropical estuarine elasmobranch has a circumtropical distribution. The U.S. population suffered decline and range constriction in the early to

mid 1900s and is now restricted to peninsular Florida. Individuals are 80 cm in total length at birth and can grow to 540 cm or greater. Rapid juvenile growth occurs during the first two years from birth. Age at maturity is estimated at 10-20 years, after reaching a total length of 340 cm. Bycatch in various commercial and recreational fisheries is viewed as the primary reason for the decline. They are found very close to shore on muddy and sandy bottoms, often in sheltered bays, on shallow banks, and in estuaries or river mouths, but habitat use is complex and varies by life history stage. Adults are opportunistic feeders and forage on a variety of fish and crustacean species. Juveniles are especially vulnerable to predation and starvation. Their preferred habitat is less than 1 meter in depth.

Pink Shrimp

The pink shrimp, basis of a multimillion dollar fishery in South Florida, is also a principal prey of sport fish and other predators in the Ten Thousand Islands. The pink shrimp spawns offshore and enters South Florida nursery areas such as the estuaries of the Ten Thousand Islands to spend its juvenile life, growing rapidly to late juveniles and young adults and then returning to offshore spawning areas and fishing grounds. Pink shrimp is the documented prey of gray snapper and spotted seatrout (Hettler, 1989). Caridean shrimp, occurring as several species in the Ten Thousand Islands, all smaller than pink shrimp, also serve as prey for many species, including pink shrimp. In complex food webs leading from mangrove and seagrass detritus and planktonic and epiphytic algae (Odum and Heald, 1972; Fry *et al.,* 1999), any one species is supporting symbiotically, competing with, or feeding many others.

Attributes People Care About

People care most of all about the species that support fisheries—for this area, the tarpon, snook, red drum, pompano, snappers, groupers, and other large sport fish, as well as pink shrimp and stone crabs. Additionally, most fishermen understand the importance of a diverse and abundant prey base to support their principal species of interest. People also can connect good fishing to productive, relatively undisturbed nursery habitat for fishery species and their prey.

Fishing is a major objective of Florida visitors whose destination is southwest Florida. The Ten Thousand Islands, the Charlotte Harbor-Caloosahatchee River area, and the SWFS are renowned fishing trip destinations. The spectacular wilderness atmosphere and teeming waters make fishing a major tourist attraction. The labyrinth of inner bays, passes, and outside waters that make up much of the Ten Thousand Islands attract backcountry-fishing enthusiasts from all over the world. Recreational fishing on the SWFS is also popular. Legal-size snapper and grouper can be found offshore over hardbottom areas in waters 40-50 feet deep or more, where gray and lane snapper are mixed with red grouper.

Recreational fishing in the Ten Thousand Islands area includes guide boat fishing, tournament fishing, and fishing from private vessels (Browder *et al.,* 1981). Backcountry fishing guides provide valuable expertise on what, where, and when to fish. Guides experienced with the geography of the area easily navigate the many confusing passes, inter-island channels, back bays, and tidal creeks, where the newcomer to the area can easily become lost. Tournaments such as the Red Snook Charity Tournament and other tournaments announced periodically on the internet by fishing clubs, or by sport fishing magazines, attract many sports fishing participants to the Ten Thousand Islands. Several tournaments that draw sportfishing visitors are organized each year.

The principal targets of inshore sport fishing are tarpon and snook, but spotted seatrout and red drum are also popular. Other species that help make the inshore trip satisfying are sheepshead, pinfish, and mojarras. Sharks are caught recreationally both inshore and offshore. The paying passenger industry is made up of independent captains who operate out of communities with hotels and resorts and also have websites. Clients hear about the fishing opportunities and guides from family and friends who have fished in South Florida. Recreational fishing activity is augmented by visitors that bring their own boats and local recreational fishers.

Commercial fishing is a traditional source of income in southwest Florida. Fishing history is written in the landings data collected since 1962. Different species have dominated the landings almost by decade. In offshore fishing, mackerel was king in the 1970s before the fishery

was declared seriously overfished in the 1980s and a series of state and federal regulations gradually were set in place. Pink shrimp, caught on both Dry Tortugas and Sanibel grounds, dominated offshore landings in Lee County. Red grouper and other snapper and grouper species became a prominent part of landings from the SWFS in the mid 1980s, but declined when gear restrictions and other regulations were imposed in both state and federal waters. The use of bottom longlines for catching reef fish species was prohibited inside 20 fathoms in the mid 1990s. Fish trap bans reached Collier and Lee counties in 2007.

Striped mullet was the major fishery species in inshore waters in both Collier and Lee counties until the monofilament gillnet was banned for most fishing operations in state waters by Constitutional amendment and became effective statewide in 1995. Mullet dominated landings records in both Collier and Lee counties in the first four decades of the record, usually accounting for more than two million pounds landed annually in Collier County and four million pounds landed annually in Lee County (compiled from records maintained by NOAA's National Marine Fisheries Service, Miami, FL). The gillnet ban affected not only mullet landings but also commercial catches of other inshore species such as spotted seatrout, pompano, and crevalle jack, which are still caught in southwest Florida, but on a smaller scale.

Based on both landings and value, averaged for the past 10 years, stone crab claws, taken from offshore waters, are the leading fishery product in Collier County today. Other major species in offshore landings in Collier County are king, cero, and Spanish mackerel (combined landings), pompano, sharks (various species), and spiny lobster. Striped mullet (marketed as flesh and roe) and blue crab are the major species harvested from inshore waters and landed in Collier County today. Averaged for the past 10 years, these species alone make up more than 96 percent of ex-vessel landings value in Collier County, i.e., $1,871,261 (compiled from records maintained by NOAA's National Marine Fisheries Service, Miami, FL).

Pink shrimp is the major fishery species landed in Lee County, making up 51 percent of landings as food shrimp, followed by red grouper and stone crab claws offshore and striped mullet (marketed as flesh and roe) and blue crab inshore (compiled from records maintained by NOAA's National Marine Fisheries Service, Miami, FL). Other species contributing the most to Lee County landings are tenpounders, brown shrimp (probably brought into the region from the northern Gulf of Mexico by migrating shrimp vessels), shrimp harvested as bait, rock shrimp, pompano, mojarras, and crevalle jack. Together, the above species make up slightly more than 95 percent of Lee County landings. Pinfish and a few other species of higher value (i.e., gag and black grouper, Atlantic littleneck and middleneck clams, king and cero mackerel, and pinfish), make up another 3 percent of Lee County landings value.

Commercial fisheries in the Ten Thousand Islands are focused on blue crab inshore and pink shrimp, stone crab, snapper, and grouper offshore. Other species such as pompano and king mackerel also are caught offshore. The two major shrimp trawling grounds are offshore near the Dry Tortugas and near Sanibel-Captiva. Shrimp trawling also occurs in shelf waters between the two main grounds wherever reefs are not present.

The passage of the Endangered Species Act and the Critical Habitat component of the Magnuson-Stevens Fishery Conservation and Management Act suggests that people care about species that are imperiled. The Ten Thousand Islands area provides important habitat for at least two fish species (smalltooth sawfish and goliath grouper), one marine mammal (West Indian manatee), and five turtle species (green, loggerhead, Kemp's Ridley, hawksbill, and leatherback) that are endangered, threatened, or otherwise of special concern. The threatened wood stork, *Mycteria americana*, also forages in the Ten Thousand Islands (Browder, 1984).

Attributes We Can Measure

Fishery landings and catch per unit of effort (CPUE) data may provide the best long-term measure of the biological productivity and well-being of southwest coast estuaries and offshore waters. Although landings data can be affected by changes in regulations, CPUE data are less affected by such changes, as long as the same gear are operating. Landings data for some species have been collected in Lee and Collier counties since 1962. Other species were gradually added to the record, and landings data have been collected for most species since at least the 1980s. Effort data (trip, days fished, or hours fished) are available with dressed weight for a few species since 1990. Red grouper, king mackerel and, possibly, cobia, appear to be the only major species with continuous annual landings and effort recorded from 1990 through 2011. The king mackerel landed in Lee and Collier counties probably were landed between Key West and the Dry Tortugas. Cobia and red grouper are better associated with the southwest Florida area, and CPUE of red grouper, in particular, might be a good indicator of habitat quality of the SWFS.

Although changes in fishery management affect landings data for certain periods, which would differ by species, annual landings data for certain species and certain periods clear of new regulatory actions could provide a view of change over time in the habitat value of the southwest coastal area. For example, landings of striped mullet from 1996 to the present and blue crab landings, possibly from the earliest records to the present, might provide good measures of estuarine habitat quality. Landings of stone crab claws might provide a good index of habitat quality of the SWFS.

The fish community in the Ten Thousand Islands has been sampled repeatedly in the past with fisheries independent sampling by otter or roller trawls, and estimates of relative abundance and density are available from some of the studies (Yokel, 1975; Carter *et al.,* 1973; Shirley *et al.,* 2005). Shirley *et al.* (2005) focused on community composition and emphasized the importance of looking at differences in community metrics. The smaller species of the lower to middle trophic levels were the principal species caught in the trawls.

Eklund (2005) proposed goliath grouper abundance as a performance measure for the reestablishment of more natural flow patterns to the Ten Thousand Islands through CERP's Picayune Strand Hydrologic Restoration Project. Because of the relationships she found between goliath grouper abundance and habitat factors, Eklund (2005) decided that the giant fish integrated the effects of habitat change that affected many other fish species. Her multiple regression model, based on four characteristics of riverine habitat, explained 92 percent of the variation in goliath grouper sampling CPUE. She noted that only when averaged over the entire sampling year and all parts of the river sampled, rather than over short stretches of space and time, was goliath grouper CPUE related to the four abiotic factors.

Sources of Change

The flow of freshwater to estuaries of the Ten Thousand Islands has been radically altered by upstream water management. The case of the estuaries downstream from Fakahatchee Strand and Picayune Strand provides a major example. Other systems that have been affected include Chokoloskee Bay, affected by channelization of the Barron River, Rookery Bay, affected by the channelization of Henderson Creek, and Naples Bay, affected by canal discharges into Gordon River. Our focus is on the system downstream from Fakahatchee and Picayune strands because of the substantial research that has centered on these areas.

Faka Union Bay, immediately west of Fakahatchee Bay, which originally received freshwater inflow from the Wood River, a small natural tributary of Picayune Strand, now receives the discharge of a major drainage canal system that originally was known as the "Golden Gate Estates" canal system. The Faka Union Canal watershed now includes Southern Golden Gate Estates (SGGE, site of the present Picayune Strand Restoration Project, located between U.S. Highway 75 and State Road 41) and part of Northern Golden Gate Estates (NGGE), which lies north of U.S. Highway 75.

The total watershed directly affected by the canal system originally encompassed an area of about 234 square miles (606 square kilometers) (Black, Crow, and Eidsness, Inc., 1974, cited in the SGGE Conceptual Plan 1996, also Wang and Browder, 1986). Another estimate, 189 square miles (490 square kilometers), was given in the Hydrologic Restoration of SGGE Conceptual Plan, South Florida Water Management District (1996) and SGGE Project

Management Plan (USACE/SFWMD, 2001) and SGGE Environmental Assessment (USACE/SFWMD, 2001). The Gordon River, which discharges into Naples Bay, is the other outlet of this extensive canal system.

The Gulf American Corporation (GAC) began construction of the roads and canals in the 1960s and completed the system, consisting of 279 miles of roads and 48 miles of canals, in the early 1970s. The canal system consists primarily of four north-south aligned major canals: Miller Canal, Merritt Canal, Faka Union Canal, and Prairie Creek Canal. The other three canals join Faka Union Canal in the southern part of Picayune Strand, north of State Road 41. Faka Union Canal continues south to discharge across a fixed weir immediately north of the Tamiami Canal at State Road 41. The Faka Union Canal continues south under State Road 41 to discharge directly into Faka Union Bay. The Faka Union Canal directly interrupted flow to the Wood River. By lowering the groundwater in the vicinity, it also affected flows to rivers east and west of Faka Union Canal.

Management of the canal during and after the GAC went bankrupt in 1978 determined the extent to which the canal system affected the hydrology of the area. After GAC left the area, the canal system was first managed by Collier County and then by the Big Cypress Basin Board of the South Florida Water Management District. The departure of water levels in Prairie Creek Canal, the easternmost canal in the system, from water levels in a well 2.5 miles east into Fakahatchee Strand (distant site) was used by Starnes and Duever (2011) to describe four hydrologic periods since 1987, when water level recorders were placed in wells along a transect running east from Prairie Creek Canal across Fakahatchee Strand. Plotted departures in water level illustrate how changes in the management of the canal system were reflected in water levels. The first period, 1987 to 1992, when there was a lack of weed management in the canals, may have captured conditions for much of the previous 20 years; it showed wide seasonal fluctuations (i.e., wet season-dry season) in water level differences between the two points. During 1983 to 1997, aquatic weed control in the canals stabilized extreme departures in water levels between the two points. Then, from about 1998 to 2003, a control structure was added to Prairie Creek Canal and wide fluctuations in departures between water levels returned. Finally, beginning about 2005,when Prairie Creek Canal was plugged in the first phase of the Picayune Hydrologic Restoration Project, the water levels in the canal departed less from the distant site and even matched it during some wet seasons, when water levels at both sites were above land surface.

Changes in Freshwater Flow to Downstream Bays

The quantity, timing, and distribution of freshwater inflow to the bay systems of the Ten Thousand Islands were changed substantially by the canal system. The canal system greatly increases the inflow of freshwater into Faka Union Bay during the wet season, decreases dry season flow, and increases the number of dry season days without any flow. The transition between wet season flow and dry season flow became more abrupt, and the natural seasonal difference in flows was accentuated. The canal system also affected other bays. It diverted surface and groundwater flow from Fakahatchee Bay, which lies directly east of Faka Union Bay and downstream from Fakahatchee Strand. The diversion reduced both wet season and dry season flow to the larger bay, although Fakahatchee Bay was influenced by low-salinity water entering from Faka Union Bay through a direct connection between the two bays. The canal system and associated road system also diverted surface and groundwater away from the small rivers and bays immediately west of Faka Union Bay, including Pumpkin River and Pumpkin Bay.

Popowski *et al.* (2004) provide the following summary. Faka Union Canal discharge records measured at the gauging station located upstream from the outfall weir are available starting in 1969. The average discharges for the period of record are 115 cubic feet per second (cfs) during the dry season (November through May) and 460 cfs during the wet season (June through October) (South Florida Water Management District, 1996). An extreme discharge of 3,200 cfs occurred shortly after the canals were built. Flows exceeding 2000 cfs occurred more recently (i.e., 1995 and 1999) (data from A. Nath, Big Cypress Basin Board).

Pressures Linked to Changes

Freshwater inflow affects many environmental conditions in the downstream estuary (Figure 1). It establishes salinity gradients, temperature gradients, and gradients in turbidity and nutrients. Furthermore, it affects both vertical and horizontal circulation, which affect, among other things,

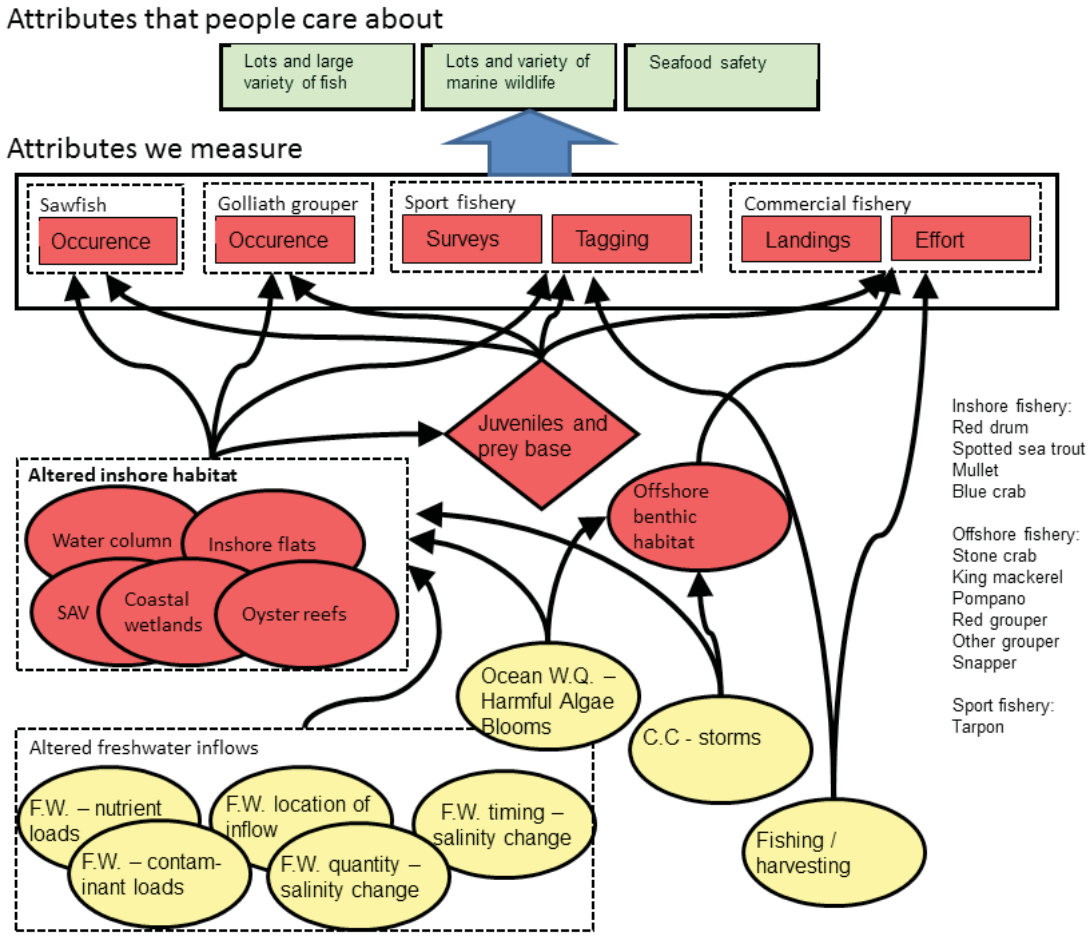

Figure 1. Fish and shellfish submodel diagram for the Southwest Florida Shelf subregion.

particle (and ichthyoplankton) transport and concentrations of dissolved gases, especially oxygen.

Since salinity and circulation are features of estuarine animal habitat, the habitat of fish, crabs, and shrimp was changed. Studies of changes in both faunal habitat and the fauna have focused on comparing Faka Union Bay with other nearby bays thought to have been less impacted by the canal system than Faka Union Bay, which receives the direct discharge of the canal system. While it has become clear that these other bays also have been impacted, the comparisons are still useful.

Most studies of the biological effects of changes in freshwater inflow in the Ten Thousand Islands have focused on the effect on fishes of changes in salinity patterns. Salinity is one dynamic dimension of fish habitat. Dissolved oxygen is another dynamic dimension. Relatively fixed features that determine fish habitat include bottom contours, bottom vegetation, shoreline configuration, and shoreline vegetation. Optimum habitat for any one species occurs where favorable salinity and favorable bottom or shoreline features overlap. Ideally, the salinity gradient provides favorable habitat somewhere in the estuary for a spectrum of fauna with different salinity requirements. Changes in freshwater inflow from the natural pattern can shift salinity zones to areas of less than favorable bottom or shoreline habitat and constrict salinity zones so that fewer species and fewer individuals within species can be accommodated with the salinity they need (Browder and Moore, 1981).

Changes in Salinity

Examination of three years of 30-min-interval salinity data for Faka Union Bay and a reference site in Fakahatchee Bay/

Fakahatchee River collected by the Rookery Bay Natural Estuarine Research Reserve indicates both spatial and temporal changes in salinity patterns as a result of changes in freshwater inflow regimes (Popowski *et al.,* 2004). Shirley *et al.* (2005) summarized salinity data from faunal studies conducted over several decades (early 1970s, early 1980s, and early 2000s) and noted that salinity in Faka Union Bay was, on average, 6-10 units lower than salinity in the other bays during the three periods.

Wang and Browder (1985, 1986) developed a hydrodynamic model of Faka Union and Fakahatchee bays that showed qualitatively and quantitatively how salinity zones shifted and zonal areas changed as a function of magnitude of freshwater inflow. Faunal models based on data from Browder *et al.* (1986) were used to show the effect on faunal abundance of changes in salinity-band area under different freshwater inflows (Browder and Wang, 1987). In a later study, Wang and Browder (2004) used their hydrodynamic model and updated faunal models from their earlier work to show that faunal abundance was substantially higher under freshwater flow regimes mimicking the natural pattern. The natural pattern for the same period was approximated by a natural-system version of the hydrologic model used to approximate the hydrologic function of the area (MIKE SHE hydrological model, as described in USACE/SFWMD, 2004). In model simulations, the "Tentatively Selected Plan" for the Picayune Hydrologic Restoration Project showed high faunal abundance similar to that of the natural system.

Both Eklund (2005) and Shirley *et al.* (2005) quantified salinity variation in their work, proposing that the rate of change in salinity rather than salinity, per se, was an important factor influencing fish well-being and abundance. In a regression relationship with goliath grouper sampling CPUE, Eklund (2005) found that salinity change was one of four factors explaining variation in CPUE. The more important factors were bathymetric complexity, proportion of the shoreline eroded, and proportion of measured time that dissolved oxygen concentration was less than 2 ppm.

Changes in Dissolved Oxygen Concentrations

Eklund (2005) found that the waterways she sampled differed in the percent of time that measured dissolved oxygen concentrations were below 2 ppm. The upper parts of the Pumpkin and Wood rivers always had minimum dissolved oxygen concentrations less than 0.35 ppm, and their middle sections had minimum dissolved oxygen concentrations less than 1, except toward the end of the wet season. Not only was grouper CPUE negatively correlated with the period of measured time that conditions were anoxic, but also crabs and catfish caught in sampling traps in the rivers with the greatest percent of time anoxic were always dead. Noting the disparity in goliath grouper CPUE among the six natural flow-ways, Eklund (2005) concluded that the rivers that were connected to upstream water sources were the productive ones because freshwater flow provided circulation that reduced the frequency and duration of anoxic events.

Changes in Physical Habitat

Changes in the freshwater inputs to the many small bays of Ten Thousand Islands led to changes in physical features of the rivers and estuaries. Eklund (2005), examining habitat factors that influenced the abundance of goliath grouper in six small rivers and three canals of the Ten Thousand Islands, documented differences in habitat structure among waterways. Some had substantial bathymetric variation compared to others, and some had a high proportion of shoreline that was eroded away below the surface, creating an overhang. Canals and small rivers did not separate cleanly based on these differences. In fact, one canal, which she referred to as 92 East (based on its relation to State Road 92), had the second highest proportion of eroded shoreline, 59 percent (second only to Little Wood River, 70 percent), whereas some of the creeks had almost none. While all of the canals had relatively flat bathymetry, a few of the rivers did also. Loss of freshwater flow from their headwaters due to construction of the Faka Union canal system may have prevented bank erosion in some of the small rivers, making them less suitable goliath grouper habitat. Faka Union Canal was poor grouper habitat on three counts—high salinity variability, lack of eroded shoreline, and lack of bathymetric complexity—but had good dissolved oxygen concentrations because of its freshwater inflow.

The eroded banks of mangrove shorelines provide prized habitat for many species. Large numbers of goliath grouper, gag grouper, snook, and gray snapper have been seen in these overhangs (Eklund, 2005). Rocky depressions provide another type of habitat for these species. The overhangs, in particular, are rich with small fish and other small prey

(Eklund, 2005). Therefore, an absence of such features may reduce the abundance of other fauna in addition to goliath grouper.

Changes in Bottom Vegetation

SAV may be a component of another part of this overall report; however, it is mentioned here because it is an important aspect of fish habitat and because observations were available from fish studies. Observations from several faunal studies (Carter *et al.,* 1973; Yokel, 1975; Browder *et al.,* 1986) suggest that the seagrass cover in Faka Union Bay and other nearby bays declined substantially since the early 1970s post Faka Union Canal construction. Based on quantitative information in Carter *et al.* (1973), we calculate that SAV average dry weight in about 1972 measured 44.61 kg/ha in Faka Union Bay, compared to 51 kg/ha in Fakahatchee Bay. Yokel (1975) also found substantial amounts of seagrass in Fakahatchee Bay. However, Browder *et al.* (1986), conducting trawl sampling in the area 10 years later, found little seagrass in either Faka Union or Fakahatchee bays. Their qualitative analysis of the associated seagrass bycatch in trawl collections suggested there was more seagrass in Pumpkin Bay than the other two bays. Colby *et al.* (1985) reported no seagrass bycatch in 97 percent of their trawl collections in nine bays of the Ten Thousand Islands, including Faka Union and Fakahatchee. According to Popowski *et al.* (2004), seagrasses associated with open water habitat are not extensive in the Faka Union Bay region but are locally abundant in the shallow waters off the outermost islands along the Gulf edge of the Ten Thousand Islands. Seagrass beds are extensive in the shallow water of Gullivan Bay south of Cape Romano. Popowski *et al.* (2004) surmised that "frequent freshets and long periods of extreme low salinity may have contributed to loss of seagrass in Faka Union and Fakahatchee bays."

Change in Oyster Reef Habitat

Intertidal and submerged oyster reefs form another type of bottom habitat important to fish, crabs, and shrimp, many of which settle out of the plankton onto the reef at early life stages. The Ten Thousand Islands have an extensive amount of oyster reefs. Over 300 macrofauna species can live in or associated with oyster beds, and over 40 species may live in a single oyster bed (Wells, 1961).

Small crabs and shrimp of many species live in the crevices between oyster shells. The skillet fish (*Gobiesox strumosus*), which was abundant in ichthyoplankton catches but rarely caught in trawls (Browder *et al.,* 1986, 1988) is an oyster reef associate. Red drum, an important sport fish species in the Ten Thousand Islands, is a commonly recognized inhabitat of oyster reef areas.

Change in Area of Overlap of Favorable Physical and Dynamic Habitat Features

The overlap of favorable salinities with favorable structural features creates the optimum habitat for a given species (Browder and Moore, 1981) or, in some cases, a given life stage within a species. Freshwater inflow provides a salinity range in which favorable salinities overlap with beneficial structural habitat to create optimal habitat for a number of species.

Favorable habitat relates not only to the salinity at any given place and time but also to the rate of change in salinity from one place to another (which affects habitat area) and one time to another, which affects the ability of the organism to maintain osmotic stability (e.g., Serafy *et al.,* 1997, regarding fish). Eklund (2005) found that, in general, canals had higher rates of salinity change than creeks and rivers, but there were exceptions. For example, 92 Canal East had a rate of change more typical of creeks and rivers, whereas Blackwater River and Royal Palm River had relatively high rates of salinity change.

Dissolved oxygen concentrations represent another dynamic dimension of faunal habitat. Eklund (2005) found that dissolved oxygen concentrations on the annual and river scale affected goliath grouper sampling CPUE and size. Dissolved oxygen concentrations at the time and place where sampling traps were set killed species such as crabs and catfish that were caught.

Status and Trends: Changes in Fish, Shrimp, and Crabs

Fishery statistics can reflect changes in the quality of fishery habitat. Several indicators based on fisheries were proposed in the Attributes We Can Measure section. Figures 2 and 3 show the CPUE of the red grouper handline fishery from 1990 through 2011 and Lee County stone crab landings and value from 1962 to 2011.

There are no before-canal studies of Faka Union Bay; however, several investigators have compared fish communities in Faka Union Bay and nearby less-impacted bays to approximate the difference between pre- and post-drainage Faka Union Bay fish communities. The results of the studies agreed that relative abundance of fish, shrimp, and crabs in Faka Union Bay was lower overall than in comparative systems. Carter *et al.* (1973) found that the abundance of trawl-caught fish was greater in Fakahatchee Bay than in Faka Union Bay. Browder *et al.* (1986) found that five of the 10 dominant trawl-caught fish species were significantly more abundant in Pumpkin Bay than in Faka Union Bay, and four of these 10 species were significantly more abundant in Pumpkin Bay than in Fakahatchee Bay. The six dominant trawl-caught macroinvertebrate species (including pink shrimp and blue crab) differed in abundance even more markedly between Faka Union Bay and one or both of the other two bays. Colby *et al.* (1985), in a comparison of forage fish communities in Faka Union Bay (Strata I) to that of eight nearby bays to the east (Strata II) and the west (Strata III), found that relative fish densities were lower in Faka Union Bay than in comparable habitats in the other bays in 11 out of 12 cases. Furthermore, they noted that, with the onset of the rainy season, fish densities declined and the decline was greatest in Faka Union Bay (83 percent, versus 70 percent, and 50 percent).

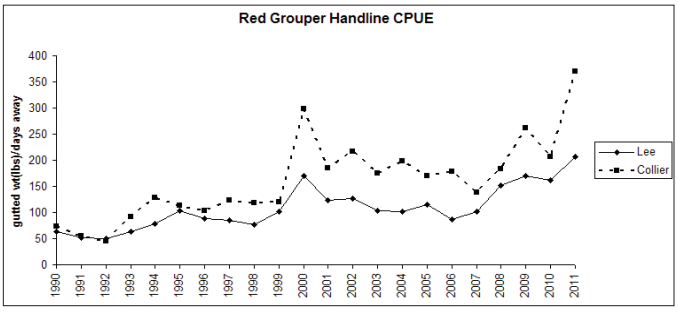

Figure 2. Long-term trend in red grouper catch per unit effort in Lee and Collier counties.

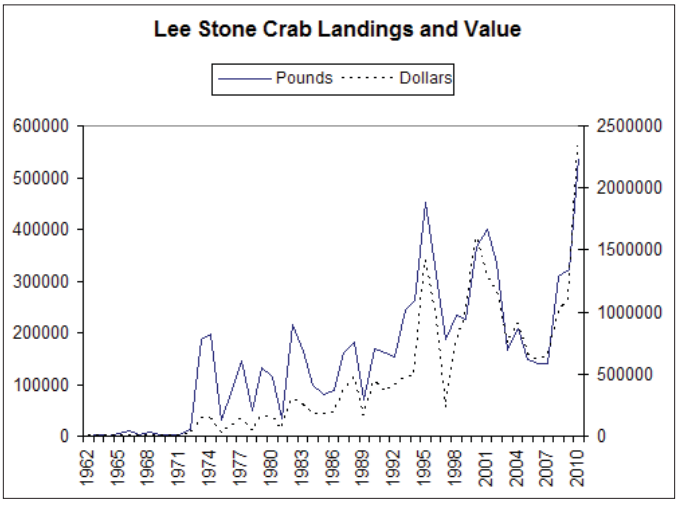

Figure 3. Long-term trend in stone crab landings in Lee and Collier counties.

Shirley *et al.* (2005) summarized the fish species caught in earlier studies, noting that Carter *et al.* (1973) employed seines, surface trawls, and otter trawls, and both surface and otter trawls were used by Colby *et al.* (1985) and Browder *et al.* (1986). Fish species listed as dominants in one or more of these studies included bay anchovy (*Anchoa mitchilli*), pinfish (*Lagodon rhomboides*), silver jenny (*Eucinostomus gula*), pigfish (*Orthopristis chrysoptera*), silver perch (*Bairdiella chrysoura*), yellowfin menhaden (*Brevoortia smithi*), and scaled sardine (*Harengula jaguana*). Use of seines and surface trawls led to the greater number of species ordinarily found in the upper water column rather than demersally (e.g., bay anchovy, yellowfin menhaden).

Based on ordination analysis, Colby *et al.* (1985) concluded that most of the dominant species had salinity optima at intermediate to high salinities rather than low salinities. Colby *et al.* (1985) decided that salinity was not the only factor that depressed fish abundance in Faka Union Bay because fish abundance was lower there in May 1983 when salinities were comparable in all estuaries. Perhaps changes in bottom vegetation were responsible for the differences.

Both Browder *et al.* (1986) and Colby *et al.* (1985) commented that Faka Union Bay did not have a unique fish community but only lower densities of the same species found in the other bays. Apparently, when the habitat of these species in Faka Union Bay became more constricted,

they did not disappear to be replaced by other species as the dominants—fish abundance simply declined overall.

Shirley *et al.* (2005) noted that the previous studies had focused on determining differences in abundance rather than differences in community structure. Shirley *et al.* (2005) used multivariate analysis techniques to explore differences in community characteristics between Fakahatchee Bay, considered to be the reference estuary, and the two disturbed estuaries, Faka Union Bay and Henderson Creek. They divided the study period into eight segments: early dry, late dry, early wet, and late wet in each year. Based on an analysis of similarities, they concluded that Fakahatchee Bay species composition was significantly different from species composition in the other two estuaries during all seasons except the late wet season. Overall, in one season or another, 34 unique species contributed most to the species composition differences between the reference estuary and the estuaries with altered freshwater inflow. More than 75 percent of these species were in greater abundance in the reference estuary, Fakahatchee Bay. Carter *et al.* (1973) found a greater diversity, as well as a greater abundance of fish, in Fakahatchee Bay compared to Faka Union Bay.

The changes in freshwater flow to the estuaries of the Ten Thousand Islands may have affected gamefish species, as typified by snook. Carter *et al.* (1973) found that tidal streams were a major nursery area for young snook. Shallow brackish stream habitats provided young snook with an abundant supply of small forage organisms, flowing water, low salinities, favorable water temperatures, and a general absence of larger piscivorous predators. Presumably, habitat for young snook would shrink where the flow of freshwater is diverted from creeks to canals. Any diminishment of principal prey species might also affect young snook.

Topics of Scientific Debate and Uncertainty

Uncertainty exists about the effects of Picayune Hydrologic Restoration on estuaries, despite studies suggesting negative effects of the canal system on not only Faka Union Bay but all the other bays in the area, including Fakahatchee Bay to the east and bays from Pumpkin Bay to Royal Palm Bay to the west.

Uncertainty exists over the effect of hydrologic restoration of Picayune Strand on the future invasions of downstream estuaries by Mayan cichlids, lionfish, and other invasive exotic species.

Acknowledgments

David Gloeckner, National Marine Fisheries Service (NMFS), Miami, Florida, provided the fishery data from which summaries were compiled for this report. Tom Herbert, NMFS Port Agent, Ft. Myers, answered many questions from the author and helped her characterize the southwest Florida fisheries.

References

Black, Crow, and Eidsness, Inc. 1974. Hydrologic study of the Gulf American Corporation. Canal Network, Gainesville, FL. Project No. 449-73-53.

Browder, J.A. 1984. Wood stork feeding areas in southwest Florida. Florida Field Naturalist, 12:81-96.

Browder, J.A., and D. Moore. 1981. A new approach to determining the quantitative relationship between fishery production and the flow of freshwater to estuaries. *Proceedings, National Symposium on Fresh Water Inflow to Estuaries,* San Antonio, TX, September 1980, 403-430.

Browder, J.A., and J.D. Wang. 1987. Modeling water management effects on marine resource abundances in Faka Union Bay, Florida. *Proceedings, Symposium on the Ecology and Conservation of Wetlands of the Usmacinta and Grijalva Delta*, Villahermosa, Tabasco, Mexico, February 2-6, 1987, 21 pp.

Browder, J.A., J.C. Davis, and E. Sullivan. 1981. Paying passenger recreational fisheries of the Florida Gulf coast and Keys. Marine Fisheries Review, 43(8):12-20.

Browder, J.A., A. Dragovich, J. Tashiro, E. Coleman-Duffie, C. Foltz, and J. Zweifel. 1986. A comparison of biological abundances in three adjacent bay systems downstream from the Golden Gate Estates canal system. NOAA Technical Memorandum, NMFS-SEFC-185, 26 pp.

Browder, J.A., J. Tashiro, E. Coleman-Duffie, and A. Rosenthal. 1988. Comparison of ichthyoplankton migration rates into three bay systems of the Ten Thousand Islands affected by the Golden Gate Estates canal system. Final Report to South Florida Water Management District, Contract #156-M88-0172-A3.

Carter, M.R., L.A. Burns, T.R. Cavender, K.R. Dugger, P.L. Fore, D.B. Hicks, H.L. Revells, and T.W. Schmidt. 1973. Ecosystem analysis of the Big Cypress swamp and estuaries. U.S. Environmental Protection Agency, Region IV, Atlanta, GA, Report EPA 904/9-74-002.

Colby, D.R., G.W. Thayer, W.F. Hettler, and D.S. Peters. 1985. A comparison of forage fish communities in relation to habitat parameters in Faka Union Bay, Florida and eight collateral bays during the wet season. NOAA Technical Memorandum, NMFS-SEFC-162, 87 pp.

Eklund, A.M. 2005. Habitat affinities of juvenile goliath grouper to assess estuarine conditions. In *Estuarine Indicators,* S.A. Bortone (ed.). CRC Press, Boca Raton, FL, 393-407.

Fry, B., P.L. Mumford, and M.B. Robblee. 1999. Stable isotope studies of pink shrimp (*Farfantepenaeus duorarum Burkenroad*) migrations on the southwest Florida Shelf. Bulletin of Marine Science, 65:419-430.

Hettler, W.F., Jr. 1989. Food habits of juveniles of spotted seatrout and gray snapper in western Florida Bay. Bulletin of Marine Science, 44:155-162.

Jannke, T.E. 1971. Abundance of young sciaenid fishes in Everglades National Park, Florida, in relation to season and other variables. University of Miami Sea Grant Program, Sea Grant Technical Bulletin, 11:1-128.

Koenig, C.C., F.C. Coleman, A.M. Eklund, J. Schull, and J. Ueland. 2007. Mangroves as essential fish habitat for goliath grouper (*Epinephelus itajar*a). Bulletin of Marine Science, 80(3):567-586.

Odum, W.E., and E.H. Heald. 1972. Trophic analyses of estuarine mangrove community. Bulletin of Marine Science, 22:671-738.

Peters, K.M., and R.H. McMichael, Jr. 1987. Early life history of the red drum, *Sciaenops ocellatus* (*Pisces: Sciaenidae*), in Tampa Bay, Florida. Estuaries, 10:92-107.

Popowski, R., J.A. Browder, M. Shirley, and M. Savarese. 2004. Hydrological and ecological performance measures and targets for the Faka Union canal and bay. Final Draft Performance Measures: Faka Union Canal. U.S. Fish and Wildlife Service, Technical Document, 22 pp.

Serafy, J.E., K.C. Lindeman, T.E. Hopkins, and J.S. Ault. 1997. Effects of freshwater canal discharge on fish assemblages in a subtropical bay: Field and laboratory observations. Marine Ecology Progress Series, 160:161-172.

SFWMD (South Florida Water Management District). 1996. Hydrological restoration of Southern Golden Gates Estates. Final Report, Big Cypress Basin Board, 206 pp.

Shirley, M., P. O'Donnell, V. McGee, and T. Jones. 2005. Nekton species composition as a biological indicator of altered freshwater inflow into estuaries. In *Estuarine Indicators*, S.A. Bortone (ed.). CRC Press, Boca Raton, FL, 351-364.

Sih, A., G. Englund, and D. Wooster. 1998. Emergent impacts of multiple predators on prey. Trends in Ecology and Evolution, 13:350-355.

Starnes, J., and M. Duever. 2011. Picayune Strand Restoration Project: Lessons learned. Presentation at the March 24, 2011 RECOVER Leadership Group (RLG) meeting. South Florida Water Management District, Ft. Myers.

USACE/SFWMD. 2001. Southern Golden Gates Estates hydrologic restoration plan. Central and Southern Florida Project. Comprehensive Everglades Restoration Plan. Final Draft, U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL and South Florida Water Management District, Big Cypress Basin, Naples, FL, 130 pp. (available at http://etdmd1.com/pdfs/I-75-Interchange-at-Everglades-Blvd-Dispute-Resolution/Documents/6%20-%20CERP%20Project%20Management%20Plan%20SGGE%20Hydrologic%20Restoration%20Project.pdf).

USACE/SFWMD. 2004. Picayune Strand Final Project Implementation Report and EIS. Appendix A, Hydrologic and Hydraulics. U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL, and South Florida Water Management District, Ft. Myers, FL.

Wang, J.D., and J.A. Browder. 1985. Canal discharge impacts on Faka Union Bay. In *Hydraulics and Hydrology in the Small Computer Age,* W.R. Waldrop (ed.). American Society of Civil Engineers, New York, Volume 1, 141-146.

Wang, J.D., and J.A. Browder. 1986. Simulation of salinity distributions in Faka Union Bay in relation to freshwater inputs. Final Report, U.S. Army Corps of Engineers, Jacksonville District on Agreement AJPD/MOA-84-1. NOAA/National Marine Fisheries Service/Southeast Fisheries Science Center, Miami, FL, Volume 1, 30 pp.

Wang, J., and J.A. Browder. 2004. Simulation and analysis of monthly salinity patterns resulting from alternative configurations of the Golden Gate Estates Restoration Project. Final report to the South Florida Water Management District on Agreement C-13401-A01. NOAA/National Marine Fisheries Service/Southeast Fisheries Science Center, Miami, FL, 13 pp.

Wells, H.W. 1961. The fauna of oyster beds with special reference to the salinity factor. Ecological Monographs, 31:239-266.

Yokel, B.J. 1975. A comparison of animal abundance and distribution in similar habitat in Rookery Bay, Marco Island, and Fakahatchee on the southwest coast of Florida. Preliminary Report, The Conservation Foundation, Washington, DC.

Zale, A.V., and S.G. Merrifield. 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (south Florida): Ladyfish and tarpon. U.S. Fish and Wildlife Service, Biological Report 82(11.104)/U.S. Army Corps of Engineers, TR EL-82-4, 17 pp.